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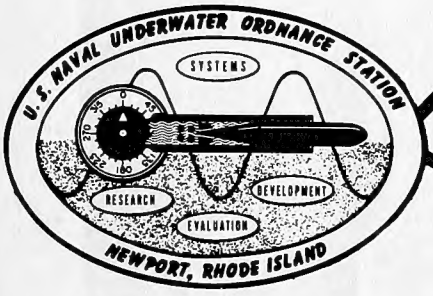
LAGRANGIAN CURRENT MEASUREMENTS IN THE NORTHEAST PROVIDENCE CHANNEL AND THE TONGUE OF THE OCEAN, BAHAMAS

14 February to 6 March 1963
FINAL REPORT

April 65



U.S. NAVAL
UNDERWATER ORDNANCE STATION
NEWPORT, RHODE ISLAND

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U. S. NAVAL UNDERWATER ORDNANCE STATION
NEWPORT, RHODE ISLAND

TECHNICAL MEMORANDUM

LAGRANGIAN CURRENT MEASUREMENTS IN THE NORTHEAST PROVIDENCE CHANNEL AND THE TONGUE OF THE OCEAN, BAHAMAS

14 February to 6 March 1963
FINAL REPORT

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April 1965

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WEPTASK Assignment No.
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FOREWORD

In the Atlantic Undersea Test and Evaluation Center development program, the Naval Underwater Ordnance Station (NUOS) is responsible for the design, installation, test and evaluation of an underwater weapons tracking range. For greater accuracy, tracking data on test vehicles must be correlated with the oceanographic environment. In cooperation with the Woods Hole Oceanographic Institution, NUOS obtained water current data during February and March 1963 in the Northeast Providence Channel and the Tongue of the Ocean, Bahamas.

A preliminary report (TM No. 306 dated September 1963) described the purpose of the cruise, the parachute drogue system employed, and the navigational equipment used in tracking the drogues. TM No. 306 also included the raw data obtained on the cruise.

This final report presents an analysis of the data with emphasis on such factors as deep water motion, eddy motion, and current shear. This work was accomplished under BUWEPS Task Assignment No. RUTO-3E-000/219 1/SF009-03-02 and ASW Oceanographic Research RU22-2E-000/219 1/R004-03-01.

ABSTRACT

The U. S. Naval Underwater Ordnance Station (NUOS) is responsible for the installation of a weapons range in AUTEC (Atlantic Undersea Test and Evaluation Center). Since this work requires a knowledge of the environmental factors affecting deep water tracking, a program was established to gather water current data in the Northeast Providence Channel and the Tongue of the Ocean, Bahamas. Measurements were taken during February and March 1963 by tracking a total of 27 parachute drogues placed at various depths (10 to 1500 meters) along five transects in the areas selected. Over 500 position fixes were taken using a Decca Hi-Fix navigation system.

Although water motion in the Tongue is of necessity related to water motion in the Northeast Providence Channel, it is not apparent what dynamic regime exists in the Tongue for a given dynamic regime in the channel (and vice versa). This conclusion is based on the complex flow patterns exhibited by deep drogues set along the entrance to the Tongue (eddy motion was observed at depths of 600 and 1500 meters). In other words, if the current structure were well known in the Northeast Providence Channel, it would still be most difficult to predict the current structure in the Tongue of the Ocean.

Current speed and vertical current gradients generally decreased in magnitude from the Northeast Providence Channel to the Tongue. There was a net in-channel flow along both transects located in the Northeast Providence Channel, although outflow could have occurred at depths where no measurements were made. Variability in current speed exhibited by individual drogues indicated a turbulent current structure.

The circulation in the Tongue is also turbulent in nature; i.e., there is no well-defined mean motion such as that found in the Gulf Stream. It is, therefore, extremely difficult to predict the current structure over relatively short periods (two or three tidal cycles).

Analysis of all current data indicates that it may be necessary to monitor current information on the AUTEC weapons range prior to, during, and after tracking experiments in order that the dynamic oceanographic environment can be correlated with tracking data on the test vehicles.

ACKNOWLEDGEMENT

Special thanks are due Mr. D. H. Shonting (NUOS) and Mr. J. Bruce of the Woods Hole Oceanographic Institution for sharing the responsibility of this work and offering many helpful suggestions.

Thanks are also due to Mr. Seward Johnson, the owner, and to the captains and crews of the OCEAN PEARL and R/V H. J. W. FAY for their untiring efforts in carrying out this work.

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INTRODUCTION

Since accurate tracking of test vehicles in the AUTEC (Atlantic Undersea Test and Evaluation Center) deep water range depends in part on correlating the effects of the dynamic oceanographic environment with data obtained by the underwater instrumentation, additional information on these environmental factors is required. In addition, the results of past current measurements have been relatively unfruitful, largely because of inadequate planning and lack of concentrated coverage.

To learn more about the currents in the AUTEC area, the Naval Underwater Ordnance Station, in cooperation with the Woods Hole Oceanographic Institution, set and tracked parachute drogues in the Northeast Providence Channel and selected areas of the Tongue of the Ocean, Bahamas. These measurements were made during the period 14 February to 6 March 1963.

A preliminary report (TM No. 306 dated September 1963) described the purpose of the program, the design of the drogue system, and the navigational equipment used in tracking the drogues. An analysis has been made of the raw data presented in TM No. 306. This final report provides at least a partial answer to the following questions:

1. Can the motion of the water in the Northeast Providence Channel be traced to the motion of the water in the Tongue of the Ocean (or vice versa)?

2. What is the mixing length (radius) of the predominant eddies in the Tongue of the Ocean?

3. What is the general magnitude of horizontal and vertical current gradients?

4. To what extent (and on what time scale) do turbulent shears (normal to the bank walls) cause mixing and transport of bank water into the AUTEC region?

5. How is the wind drift pattern related to tidal data?

RESEARCH VESSELS

Two vessels were used during the program. The OCEAN PEARL, a privately owned ketch capable of speeds up to 9 knots under power, was used by the Woods Hole Oceanographic Institution under the direction of Mr. John Bruce, WHOI. The H.J.W. FAY, a research vessel capable of speeds up to 18 knots, was used by the Naval Underwater Ordnance Station (on contract from Marine Acoustical Services, Inc., Miami, Florida) under the direction of Mr. G. S. Cook, NUOS.

Both vessels were equipped with Decca navigation radar and standard ship-to-shore transceivers. Decca Hi-Fix receivers were installed on each vessel and used in combination with the radars to track the drogues. Thus, if one system failed, tracking could be continued with the other system alone.

With two vessels tracking their respective drogues simultaneously at various distances from each other, it was possible to make synoptic current measurements (using drogues) for the first time in the area. In addition, the program was not interrupted when one vessel had to return to port. This was important, since quasi-continuous measurements were desirable in order to determine meaningful flow patterns.

CURRENT MEASUREMENT AREAS

Five areas were selected in the Northeast Providence Channel and the Tongue of the Ocean, and water current measurements were taken along transects in these areas (figure 1).

The first transect (T1) was between Northern Eleuthera (Egg Island) and Great Abaco Island (Hole-in-the-Wall). This transect was selected to define water motion at the entrance to the Northeast Providence Channel.

The second transect (T2) was along a line bearing 343°T from Old Fort Point (New Providence Island) and terminating east of the Berry Islands at the 100 fathom curve.

The third transect (T3) extended eastward from the longitudinal axis of the Tongue of the Ocean (broken line in figure 1) to the east bank along latitude 24° 40'N.

The fourth transect (T4) was parallel to the west bank of the Tongue about three miles east of Middle Bight on Andros Island. The drogues set along T4 were tracked simultaneously with those set along T3.

The fifth transect (T5) extended westward from the longitudinal axis of the Tongue to the west bank along latitude 24° 15'N. Drogues set along T5 were also tracked simultaneously with the drogues set along T3 (after tracking was completed along T4).

A total of 27 drogues were set and tracked along these five transects, and 19 of the surface floats were recovered. The drogues were placed at predetermined depths to provide information on the character and velocity of the water currents throughout the water column. Table 1 shows the number of drogues tracked along each transect, the depth at which each drogue was set, and the total tracking time per drogue.

Table 1. Drogues, Depths, and Tracking Time

Transect	Drogue Identification	Depth (Meters)	Total Tracking Time (hours)	Surface Float
1	Victor	10	93.0	Recovered
	3	200	81.3	Recovered
	2	200	20.4	Lost
	4	600	26.1	Lost
	8	600	70.5	Recovered
	X-ray	1500	89.1	Recovered
	Yankee	1500	51.1	Recovered
	Zebra	1500	36.0	Lost
2	Foxtrot	10	67.7	Lost
	3-II	10	48.0	Lost
	Mike	200	95.1	Recovered
	Romeo	200	96.0	Recovered
	Golf	600	99.3	Recovered
	Tango	600	94.8	Recovered
	1	1500	70.4	Lost
	SR	1500	96.7	Recovered
3	Romeo II	200	121.5	Recovered
	3-III	500	65.8	Recovered
	Tango II	1000	72.0	Recovered
	SR-II	1000	66.0	Recovered
4	Charlie	10	22.5	Lost
	Kilo	10	70.8	Recovered
	Yankee II	10	47.8	Recovered
5	Papa	200	73.7	Recovered
	Uniform	500	34.5	Lost
	November	1000	74.5	Recovered
	Lima	1400	49.3	Recovered

DROGUE DESIGN AND PAYOUT

Figure 2 shows the design of the drogue system. All drogues were identical in construction. The parachute drogue presented a drag area of about 45 square meters to the current at depths where measurements were taken. This was in contrast to a drag area of about three square meters where the styrofoam float was exposed to surface water and wind.

After the surface float was launched, the specified amount of wire was payed out through an indicating meter wheel while the vessel steamed slowly upwind. When the proper amount of wire was payed out, a cheek clamp was attached to the suspension wire. The parachute and a 50-pound weight were secured to the cheek clamp, and the suspension wire was cut. The weight was then lowered over the side until the parachute shrouds carried the full weight. At this time the weight was released and the parachute was pulled downward by the weight. (The parachute is payed out exactly opposite to payout in the air; i.e., the shrouds are payed out first, the canopy being the last part to enter the water.) In all cases, it was possible to see the parachute open under water.

NAVIGATION AND TRACKING

The positions of the surface floats relative to known landmarks were determined with a Decca Hi-Fix System (Decca Navigator Company, Ltd., London), and an auxiliary fix was taken with navigation radar.

The Decca Hi-Fix is a high precision, lightweight, electronic position-fixing system, intended primarily for use at short ranges. The system is designed for hydrographic, geophysical, and other surveys in which an accuracy of less than one meter is required, and which demand the use of an electronic surveying system that is readily portable, simple to operate, and quick to install. Decca Hi-Fix receivers were temporarily installed on both vessels, and were used independently but in conjunction with the radars.

The H.J.W. FAY was equipped with a Decca 404 navigation radar, which is specified to have a frequency of 9320-9480 mc/sec and a display discrimination of 20 yards. Range scales in nautical miles are 0.75, 1.5, 3, 6, 12, 24, 48. On shorter range scales, the range ring accuracy is 1 1/2 percent of the maximum of the range used or 75 yards, whichever is the greater. The variable range marker accuracy is better than 1 percent of the range ring accuracy. The bearing resolution is ±1°. The OCEAN PEARL was equipped with a Decca 303 navigation radar, which has characteristics similar to the Decca 404. The ranges most used were 6, 12, and 24 nautical miles.

The Decca Hi-Fix "net" in the Tongue of the Ocean, shown on figure 1, consists of three land-based transmitting stations (two slave stations in conjunction with the common master station). Typical operating distances

between Hi-Fix transmitters and receivers are 5 - 35 miles. However, the receiver can be used close to the transmitting station without loss of accuracy; or at a maximum offshore range of about 100 miles, if the radiated power from the transmitting station is increased. The radiated power of the transmitting stations in the Tongue of the Ocean is sufficient to ensure a working range which is normally in excess of 50 miles over sea water. During this program, the Hi-Fix system was used at a maximum distance of about 110 nautical miles (T1 in figure 1) from the farthest slave station with fair reliability. From a nomogram it was calculated that the lane width along transect 1 was from 1700 to 1900 meters. Since the receivers were capable of reading to 1/100 of a lane, this provided an accuracy in the order of 17 - 19 meters.

A series of Decca transformation charts were available for the Tongue of the Ocean area to plot the positions of the drogue floats between 23° 50' and 24° 50' north latitude. Although there was no chart coverage for the transect in the Northeast Providence Channel, the Naval Oceanographic Office has a computer program for converting Decca coordinates to latitude and longitude, and this was used to plot the positions of the floats in these areas.

In general, the Decca Hi-Fix system, backed up by radar, was quite adequate for tracking the drogues, and the position fixes obtained were satisfactory.

DROGUE CURRENT MEASUREMENTS

Transect 1

Eight drogues were set at various depths and tracked along transect 1 (T1 in figure 1). The drogue history and data sheets are included in appendix A. Table 2 is a summary of the drogue data obtained along T1.

Table 2. Summary of Drogue Data - Transect 1

Drogue	Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Travel Time (hours)	Mean Direction (°T)
Victor	10	65.4-5.7	22.1	92.84	202
3	200	108.6-5.7	17.5	77.95	208
2	200	*288.8-38.1	77.7	14.67	186
4	600	18.0-7.7	14.9	21.80	290
8	600	*187.9-16.5	34.0	63.41	198
Zebra	1500	15.4-3.1	8.2	31.97	074
Yankee	1500	30.4-4.6	14.4	45.00	163
X-ray	1500	*146.7-8.8	13.4	69.74	179

*Questionable values

During the first 36 hours of tracking, drogue Victor (10 meters) traversed a cyclonic path (radius about 7 kilometers), then coursed generally southward during the remainder of the tracking time.

Two drogues were set at 200 meters, drogue 2 to the north and drogue 3 to the south of drogue Victor. They exhibited a general southward motion somewhat comparable to that of drogue Victor. (See figure 3.) Drogue 2 exhibited a remarkably high speed during the second 12-hour period. This was probably due to a temporary loss of signal by the Decca receiver.

Two drogues were set at 600 meters, drogue 8 to the north and drogue 4 to the south of drogue Victor. The motions of the drogues were quite different from each other. Drogue 4 moved northward during the first 12 hours of tracking, then moved abruptly toward the west during the last 14 hours of tracking. Drogue 8 was set before drogue 4. During the first 12 hours of tracking, drogue 8 moved northward, then abruptly reversed its track and moved southward during the remaining tracking time. Thus, over the same time interval, the two 600 meter drogues were moving in opposite directions. (See figure 4.)

Three drogues were set at 1500 meters (southern part of the channel). Drogues X-ray and Yankee showed a net southerly motion, while drogue Zebra showed a net easterly or out-channel motion. This difference in direction by drogue Zebra appears to be a boundary effect caused by the proximity of the banks. (See figure 5.)

The motion of nearly all the drogues along T1 indicated a net flow into the Northeast Providence Channel at all depths. The only exception was drogue Zebra (1500 meters), which had an average speed of 8.2 cm/sec toward 074°T.

If the Northeast Providence Channel is arbitrarily divided into two equal parts by a line parallel to the long axis of the channel (figure 1), it will be noted that the drogues in the northern part of the channel had higher ranges of speed, and thus higher average speeds, than the drogues in the southern part of the channel. In either case, current speed generally decreased with increasing depth.

The direction of six of the eight drogues (between 163°T and 208°T) was toward the bank between New Providence Island and Northern Eleuthera. This bank forms the southern boundary of the channel. The motion of the drogues indicates that the flow between the Northeast Providence Channel (T1) and an area closer to the Tongue (T2) is not simple, and that it may be a complex system of eddies resulting from the bounding bank acting as a barrier to the flow.

Some of the position fixes taken close together in time appeared to be in error, resulting in extremely high current speeds, especially for drogues 2 and 8 located in the northern part of the Northeast Providence Channel. (See

data sheets in appendix A.) One probable source of error is that the receivers were used 110 nautical miles from the transmitting sites, resulting in a loss of signal strength (reference 1). In addition, a storm from the northeast with winds of 30 miles per hour interrupted tracking. (See appendix B for wind data.) The drag on the surface float due to the wind was probably sufficient to bias the drogue data.

Some current data (6 days) were obtained 40 nautical miles east of Abaco (26°06'N and 76°19'W) during late October 1962 with a Richardson-type array (by J. Hirshman, Alpine Geophysical Associates, Norwood, N.J.). Data were taken at depths of 550, 610, 915, 1220, and 2740 meters. Briefly, these data indicated that currents at 550 and 610 meters were tidal in nature, with speeds ranging from 2.5 cm/sec to 20 cm/sec. The net direction was toward the southwest. At 915 and 1220 meters the currents were still indicative of tidal motion, but this was not as definitive as at 550 and 610 meters. Current speeds were generally greater at 915 meters with a flow of from 10 to 30 cm/sec toward the south and southeast. At 1220 meters the current was steady between 15 and 20 cm/sec toward the south and southwest. At 2740 meters the current was steady at 15 cm/sec. No directions were reported at this depth.

If a steady state current regime exists east of Abaco (there is little data to support this one way or another), then it is reasonable to assume that currents in this area can affect water motion in the Northeast Providence Channel and thus in the Tongue itself.

Vertical current gradients were computed from data presented in table 2. This was accomplished by computing a velocity component parallel to the long axis of the Northeast Providence Channel from the average current velocity presented in table 2. The bearing of the long axis of the channel is 050°T-230°T.

The velocity components for the northern and southern halves of the channel are plotted against depth in figure 6. The values for the vertical current gradient are shown on the figure.

The vertical current gradients were generally greater in the northern half (drogues 2, 8, and X-ray) than in the southern half (drogues 3, 4 and Zebra) of the channel. It is important to note that at nearly all depths sampled, there was a definite in-channel (in TOTO) flow of water. The one exception was the out-channel flow at 1500 meters in the southern part of the channel. Negative gradients were shown from 200 to 1500 meters over the southern part of the channel and from 200 to 1500 meters over the northern portion, with a maximum of -6.6 cm/sec per 100 meters.

Transect 2

Eight drogues were set at various depths and tracked along transect 2 (T2 in figure 1). The drogue history and data sheets are included in

appendix A. Table 3 is a summary of the drogue data obtained along T2. The depths at which drogues were tracked were the same as the depths along T1.

Table 3. Summary of Drogue Data - Transect 2

Drogue	Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Travel Time (hours)	Mean Direction (°T)
Foxtrot	10	20.1-8.2	12.4	45.02	314
3-II	10	34.5-8.2	18.5	38.31	237
Romeo	200	38.6-5.1	13.4	53.18	243
Mike	200	32.9-5.7	11.3	46.60	228
Golf	600	25.2-1.0	9.8	99.30	175
Tango	600	44.3-0.5	5.7	92.21	092
1	1500	6.2-3.1	6.2	37.10	242
SR	1500	11.3-1.5	7.7	88.10	345

Current speeds along T2 were generally less than those obtained along T1. Directional motion was also markedly different.

Motion at 10 and 200 meters was southwesterly (into the Tongue), and the drogue tracks indicate uniformity with respect to speed and direction (figure 7). Drogue Foxtrot (10 meters), however, did not conform with the others. Position fixes indicated that the Decca receiver was not operating properly.

The tracks of drogue 3-II (10 meters), and of Mike and Romeo (both 200 meters) indicated a displacement (in the form of a hump) toward the north from a relatively uniform path (figure 7). This displacement occurred on all three drogues at the same time. The displacement began on 22 February at 0500 hours and continued until 0200 hours on 23 February. This motion did not appear to be tidal in nature, but fixes on the individual drogues were too far apart in time to substantiate this.

Motion at 10 and 200 meters was uniform and toward the Tongue, as was the case with the 10 and 200 meter drogues along T1. The water motion at these depths is probably due to a combination of flow through the Northeast and Northwest Providence Channels. (The sill depth in the Northwest Providence Channel is approximately 660 meters [reference 2]; therefore, there can be no contribution of flow from the Northwest Providence Channel at depths greater than about 660 meters in both the Tongue and the Northeast Providence Channel.)

The flow at T2 is related in a complex manner to the flow at T1, which acquires its energy from the Sargasso Sea. It is not apparent from the data how the flows in these different areas are related.

The water motion at 600 and 1500 meters was not as well defined as the motion at the shallower depths, and average speeds were less than those at 10 and 200 meters.

Drogue 1 (1500 meters) was launched in the northern part of the channel and moved 5.0 kilometers toward 242°T (following the bank contours). Drogue SR (1500 meters) was launched in the southern part of the channel and moved cyclonically toward 345°T, with a mean displacement of 20.9 kilometers. Drogue Golf (600 meters) was launched in the northern part of the channel and moved cyclonically with a mean displacement of 21.4 kilometers toward 175°T. Drogue Tango (600 meters) was launched in the southern part of the channel and had a mean displacement of 3.3 kilometers toward 092°T. (See figure 8.)

The motion of the 600 meter and 1500 meter drogues is quite complicated, exhibiting two scales of eddy motion at 600 meters and one scale of eddy motion at 1500 meters. At 600 meters the radii of the eddies are 13 kilometers for drogue Golf and 3 kilometers for drogue Tango. At 1500 meters the track of drogue SR had a radius of 13 kilometers. For an average speed of 8 cm/sec the inertia circle had a radius of 12.8 kilometers at 25°20'N.

However, since drogues 1 (1500 meters) and Tango (600 meters) did not conform to the motion of drogues SR (1500 meters) and Golf (600 meters), the presence of an eddy system could not be definitely established.

Some inaccuracy was expected (as along T1) in obtaining fixes, since the Decca receivers were being used close to the baseline in the northern part of the channel. The erratic nature of fixes for drogue Foxtrot (10 meters) confirmed this.

Vertical current gradients were computed from the data obtained along T2, using the same method as with the data from T1. Transect 2 was also divided into a northern section (drogues Foxtrot, Mike, Golf, and 1) and a southern section (drogues 3-II, Romeo, Tango, and SR).

Drogues along the northern part of the transect indicated a net motion toward the Tongue, with the greatest vertical gradient between 10 and 200 meters (figure 9). This gradient is very doubtful, due to the erratic position fixes on drogue Foxtrot.

Drogues along the southern part of T2 indicated a net motion into the Tongue at 10 and 200 meters, but at 600 and 1500 meters the net flow was out of the Tongue.

It is difficult to infer just how representative the gradients are between 600 and 1500 meters, due to the eddy motion indicated in the drogue tracks (figure 8). Motion at 10 and 200 meters was much more uniform with regard to direction.

Transect 3

Four drogues were set at various depths and tracked along transect 3 (T3 in figure 1). The drogue history and data sheets are included in appendix A. Table 4 is a summary of the drogue data obtained along T3.

Table 4. Summary of Drogue Data - Transect 3

Drogue	Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Track Time (hours)	Mean Direction (°T)
Romeo II	200	29.3-3.6	9.8	116.20	326
3-III	500	13.4-4.6	8.7	66.18	305
SR-II	1000	7.7-2.6	4.1	59.92	180
Tango II	1000	8.8-1.5	3.6	65.92	224

Current speeds were less along T3 than along T2.

Drogue Romeo II (200 meters) was launched in the eastern part of the Tongue. The drogue moved southward during the first 24 hours, executed an anticyclonic loop (diameter of 1.1 kilometer) and moved northward along the 1100 meter isobath for a 48-hour period, then moved northwesterly toward the central part of the Tongue. (See figure 10.) The average speed of drogue Romeo II while moving southward was 19.5 cm/sec, and the average speed along the northward displacement was 10.8 cm/sec.

Drogue 3-III (500 meters), which was launched approximately two hours after Romeo II, moved southward during the first 11 hours of tracking; then moved anticyclonically toward the north (along the long axis of the Tongue) parallel but to the west of Romeo II (figure 10). The average speed of 3-III moving southward was 9.3 cm/sec, and the average speed while moving northward was 8.8 cm/sec.

The motions of drogues Romeo II (200 meters) and 3-III (500 meters) were the first definite indication of a net flow of water out of the Tongue. There was one drogue (Zebra) on transect 1 and two drogues (Tango and SR) on

transect 2 which indicated a net flow out of the channel, but their motions were so erratic that one fix plus or minus the last fix on the surface float could have appreciably altered the value found for the resultant net motion (eddy motion). This is not to imply that there is no outflow from the Tongue; it simply means that for depths at which currents were measured, there was no definitive outflow from the Tongue at transects 1 and 2. Certainly, if there is a flow of water into the Tongue, there must be an outflow at some depth (possibly a depth at which no current measurements were taken).

Two drogues, Tango II and SR-II, were set at 1000 meters in the eastern and western parts of the Tongue, respectively. Both drogues indicated a net flow into the Tongue. (See figure 11.) Drogue SR-II followed the 1600-meter isobath, whereas drogue Tango II showed a very erratic course with a net motion toward the southwest. The average speed for both drogues was nearly the same. (See table 4.)

Current measurements taken the previous year (reference 3) in approximately the same area indicated a net northerly motion at 50 and 200 meters, but a net southerly motion at 500 meters. The 50 meter drogue track was remarkably similar to that of drogues Romeo II and 3-III; i.e., the drogue coursed southward during the first 11 hours of tracking, gradually veered to the east, then moved northward during the remaining tracking period.

Transects 3 and 4 were run simultaneously, and both T3 and T4 were run during a portion of transect 5.

Vertical current gradients were computed the same as before, except that the bearing of the longitudinal axis of the Tongue (340°T-160°T) was used in place of the axis of the Northeast Providence Channel.

Drogues set along T3 were located in the eastern half of the Tongue, with the exception of drogue SR-II (1000 meters), which was located in the western part of the Tongue.

Figure 12 is a diagram of the current gradients for transect 3. There was a net flow of water out of the Tongue at 200 and 500 meters, and a net flow of water into the Tongue at 1000 meters. This was indicated by both 1000 meter drogues. Negative gradients were shown from 200 to 1000 meters.

Transect 4

A series of special drogue measurements was made 4-5 kilometers east of Middle Bight in an attempt to learn more about the character of the surface currents and how closely these currents are related to the tidal motion on the banks. Of particular interest was the degree of mixing of bank water with Tongue water. Table 5 is a summary of drogue data obtained along T4.

Table 5. Summary of Drogue Data - Transect 4

Drogue	Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Travel Time (hours)	Direction
Kilo	10	3.6-63.8	13.5	70.7	See figure 13
Yankee II	10	2.2-52.9	15.8	24.3	See figure 13
Charlie	10	5.9-29.8	16.6	22.5	See figure 13

The study consisted of placing three surface (10 meter) drogues along an approximate northwest-to-southeast line and about 2 kilometers apart. The drogues were tracked for about 30 hours, with position fixes taken at intervals as short as ten minutes. The accuracy of the Decca Hi-Fix system in this area was of the order of a few meters, allowing very precise tracking.

These particular measurements were planned and conducted separately by D. H. Shonting of NUOS in support of the overall study. A detailed analysis is being made of these data, and results will be reported under separate cover at a later time. Only the salient features of the drogue motion are discussed here.

The track plots of the three drogues are presented in figure 13. Data sheets and the drogue history are included in appendix A.

Drogue Kilo was tracked from 1146 on 28 February to 1033 on 3 March, with a temporary postponement of tracking from 1245 on 1 March to 0812 on 2 March due to high winds. During the first six hours of tracking (1146 to 1824 on 28 February) Kilo moved north-northwest at an average speed of 17.1 cm/sec. During the second six hours Kilo moved west then south at an average speed of 6.8 cm/sec. During the next 12 hours Kilo moved southward at an average speed of 10.5 cm/sec, after which the tracking was delayed due to high winds. The following day Kilo was located to the southeast of the initial starting point (see figure 13), and at 1230 on 2 March Kilo was east of the position fix taken at 1241 on 28 February. Kilo then moved north-northwest and later northwest for the remaining time at an average speed of 12.6 cm/sec.

The remarkable feature of the cyclonic motion exhibited by drogue Kilo is the apparent symmetry, which is indicated by the fact that after 48 hours Kilo had nearly returned to the same position at which it was launched. It is of further interest to note the similarity between the drogue track from 1146 to 1824 on 28 Feb and that from 0812 to 1628 on 2 March.

The motion of drogue Yankee II during the first seven hours of tracking was generally toward the north at an average speed of 24.8 cm/sec. Yankee II then veered to the west, exhibiting a sawtooth pattern during the next 7-8 hours with an average speed of 8.6 cm/sec. These curious fluctuations were probably real, since the accuracy of the Decca Hi-Fix was considered less than the amplitude of the sawtooth fluctuations. During the remaining period of tracking, Yankee II moved toward the west-southwest at an average speed of 10.9 cm/sec.

Drogue Charlie moved north-northwest during the first seven hours of tracking at an average speed of 25.5 cm/sec, then gradually veered to the west. During the period from 2038 to 2301 on 28 February (when the drogue was turning to westward), the speed decreased from 16.8 to 10.0 cm/sec. The average speed during the remaining tracking time was 8.9 cm/sec.

After the delay in tracking, drogue Charlie (like drogue Kilo) was located at nearly the same position it was in some 48 hours earlier. (See figure 13.) Note also the similarity of track plots for drogues Charlie and Yankee II.

In general, the three drogues showed remarkable similarity with respect to direction, but less so with respect to speed. Figure 14 shows the average speed of the three drogues over the same time interval. There was an increasing horizontal current (speed) gradient from drogue Kilo to drogue Charlie, and throughout each individual drogue track there was considerable variability with respect to speeds. However, there appear to be three distinct forms of motion over particular time intervals (indicated by the drogue tracks) during which the speeds were relatively uniform. Note also the apparent 12-hour periodicity in the speed and the phase difference for the three drogues (figure 13).

The subsequent detailed analysis of these data should shed some light on the turbulent mixing and transport of bank water in the AUTEC area.

Transect 5

Four drogues were set at various depths and tracked along transect 5 (T5 in figure 1). The drogue history and data sheets are included in appendix A. Table 6 is a summary of the drogue data obtained along T5.

Table 6. Summary of Drogue Data - Transect 5

Drogue	Depth (meters)	Range of Speeds (cm/sec)	Average Speed (cm/sec)	Total Travel Time (hours)	Mean Direction (°T)
Papa	200	59.7 - 5.1	13.9	27.94	342
Uniform	500	*103.0 - 1.5	8.2	30.51	318
November	1000	40.2 - 7.2	14.4	29.42	325
Lima	1400	7.2 - 3.6	5.7	46.65	291

*Doubtful value

Along transect 5 all drogues indicated a net northerly flow of water out of the Tongue (figure 15). Drogue Papa (200 meters) showed an abrupt westward displacement during the last 36 hours of tracking. This was probably due to rather strong winds blowing from the east, which interrupted tracking for a day. The same displacement was noted on drogue Uniform (500 meters), but was less apparent on drogues November (1000 meters) and Lima (1400 meters). Average speeds were generally higher along T5 than along T3 (Compare tables 4 and 6.).

Drogue current observations taken the previous year (February 1962) indicated a northerly set at 200 meters with an average speed of 7 cm/sec (reference 3, p. A-25). At 500 meters the drogue moved cyclonically, with a net motion toward the west-southwest at an average speed of 6 cm/sec.

The motions of drogues November, SR-II, and Tango II (all set at 1000 meters) relative to each other were quite different. (See tables 4 and 6 and the drogue tracks.) In fact, drogues SR-II and November converged, with November moving more than three times as fast. The explanation for this is not known. The parachute had not parted from the drogue, as a tension was noted on both drogues upon retrieval.

Vertical current gradients for T5 are shown in figure 16. Note the negative gradient between 1000 meters and 1400 meters.

DISCUSSION OF RESULTS

Current speeds at all depths were generally higher along T1 than along T2. The directional motion at 10 and 200 meters was much more uniform along T2 than along T1. In practically all cases, except those previously noted, there was a net in-channel flow. The flow at T1 was apparently related to the flow at T2, but in a complex manner due to the effects of the bounding banks.

Any influence from the Northwest Providence Channel was not readily apparent from the data; however, since the sill depth of this channel (reference 2) is about 660 meters, it will have little if any effect on the water below 660 meters in the Tongue or in the Northeast Providence Channel.

Vertical current gradients were generally greater at T1 than along T2. A net out-channel flow below 1000 meters was noted in the southern part of the Northeast Providence Channel. Similarly, an out-channel flow was noted between 600 and 1500 meters along the southern portion of T2.

Drogues set along T3 gave the first clear indication of flow out of the Tongue. At 200 and 500 meters the flow was northerly out of the Tongue, whereas at 1000 meters the flow was southerly into the Tongue.

In February 1962 a series of drogue (reference 3) data measurements were made in the area of T3. In brief, these data indicated a northerly flow at 50 and 200 meters and a southerly flow at 500 meters, with average speeds of 7.6, 4.1, and 7.5 cm/sec, respectively.

Vertical current gradients were quite small along T3 compared with those found along T1 and T2. There was also a flow of water into the Tongue at 200 and 500 meters and an outflow at 1000 meters.

The shallow drogues set along transect 4 indicated that the surface currents are related to some extent to tidal motion. However, mixing of the bank water with Tongue water was not readily apparent. A detailed analysis of the data should shed more light on this subject.

Along T5 the flow of water was northerly or out the Tongue at all depths measured. A storm from the east interrupted tracking for a day. The effect of the wind on the surface floats was shown in the sharp westward displacement in the drogue tracks of Papa and Uniform.

Vertical gradients were generally greater at T5 (western part of the Tongue) than at T3 (eastern part). There was a positive gradient between 500 and 1000 meters at T5.

There was practically no eddy motion observed along T1 except for the first 36 hours of tracking drogue Victor (10 meters). This motion (figure 3) was probably due to a combination of the winds and tides.

Eddy motion was particularly noticeable along T2 at depths of 600 meters and 1500 meters. The sense of rotation of these eddies was opposite to that expected, if the flow patterns at T1 were representative of actual conditions. Moreover, if water entering the Northeast Providence Channel courses southward (as indicated in figures 3, 4, 5), then an anticyclonic eddy would be expected at T2, due to the effect of the bounding bank, rather than the cyclonic eddies shown in figures 7 and 8.

Eddy motion was not observed at T3, but a marked reversal in current direction was noted at 200 meters and 500 meters. At 1000 meters, the net flow was southerly.

The net flow along T5 was northerly with no indication of eddy motion.

Table 7 is a summary of current speed by depth for all transects.

Table 7. Average Current Speeds by Depth and Transect

Depth (meters)	CURRENT SPEED (cm/sec)				
	T1	T2	T3	T4	T5
10	22.1	12.4 18.5		13.5 15.8 16.6	
200	17.5 77.7*	13.4 11.3	9.8		13.9
500			8.7		8.2
600	14.9 34.0	9.8 5.7			
1000			4.1 3.6		14.4
1400					5.7
1500	8.2 14.4 13.4	6.2 7.7			

NOTE: Each value presented represents the average speed of one drogue.

*Questionable value

The average current speeds presented in table 7 are representative values for the given areas and depths. In particular, the average surface current velocities at T4 are considered to be quite accurate, although there are fluctuations in the velocities over periods of time much less than that of the total tracking time (see appendix A-T4). These fluctuations are real and are informative for operations taking place in the weapons range area.

Average subsurface currents are less accurate than the surface current measurements, and may be accurate to within 15 percent of the surface current.

Maximum or peak current speeds presented in the tables are at best only a first approximation to the actual current, with the exception of the surface current measurements at T5.

Precise measurements of peak current speeds, especially near the bottom, can best be made using the self-recording Richardson-type current meter.

Apparently, two separate dynamic regimes exist -- the Northeast Providence Channel area, which in itself is quite complex, and the Tongue of the Ocean. Both areas are turbulent in nature. They are related to the extent that the energy required for driving the circulation in the Tongue can come only from the Sargasso Sea via the Northeast Providence Channel, and from the Florida Straits via the Northwest Providence Channel (sill depth of 660 meters). Assuming that the current structure in the Northeast Providence Channel were known, it would still be most difficult to predict the current structure in the Tongue of the Ocean. This is due to the effect of the physiographic structure of the channel and Tongue on the water motion.

Although wind data taken during the cruise are not complete and in many cases were estimated, the wind effect on the surface floats was apparently considerable at certain previously noted times (see appendix B). Persistent northeast winds may explain in part the fact that nearly all drogues moved southerly into the channel along T1. Wind effects were also quite noticeable on the surface floats of the drogues along T3 and T5 during the latter period of tracking.

CONCLUSIONS

Based on the data presented herein, the following conclusions are drawn with respect to the five questions posed at the beginning of this report.

1. Although the water motion in the Northeast Providence Channel is of necessity related to the water motion in the Tongue, it is not apparent what dynamic regime exists in the Tongue for a given dynamic regime in the Northeast Providence Channel (or vice versa). The complex flow patterns exhibited by the deep drogues at T2 support this. In other words, if the current structure were well known in the Northeast Providence Channel area, it would still be most difficult to predict the current structure in the Tongue.

2. The only eddy motion observed was found along T2 at depths of 600 and 1500 meters. The two eddies at 600 meters had radii of 3 and 13 kilometers; the eddy at 1500 meters had a radius of 13 kilometers. Although eddy motion was not observed at the other transects, it may occur from time to time in either the Northeast Providence Channel area or the Tongue of the Ocean. The duration of the eddies would depend on the differential force coupling between the two areas.

3. Vertical current gradients generally decreased in magnitude from the Northeast Providence Channel to the Tongue of the Ocean. The maximum positive (increase with depth) and maximum negative (decrease with depth) gradients were found at T1, whereas the minimum positive and negative gradients were found along T2. Vertical current gradients in the Tongue varied from +0.7 to -2.1 cm/sec per 100 meters. Although vertical gradients may be stronger or weaker from time to time, especially in the upper 500 meters, these are probably representative values of the mean.

4. Conclusions regarding tidal motion and the mixing of bank water with Tongue water in the surface layer will be discussed in a subsequent report.

5. Relatively little tidal data has been gathered in the Tongue, precluding any accurate analysis of wind drift of the surface water in relation to tidal data.

In addition to the above comments pertaining to the aforementioned questions, the following conclusions have been reached.

Current speeds generally decrease in magnitude from the Northeast Providence Channel to the Tongue of the Ocean.

The net in-channel flow observed along the first two transects is probably not a steady state phenomenon, although outflow could have occurred at depths at which no measurements were made.

Variability in current velocity exhibited by individual drogues is indicative of a turbulent current structure.

The circulation in the Tongue of the Ocean is turbulent in nature; that is, there is no well-defined mean motion such as one finds in the Gulf Stream.

It is, therefore, extremely difficult to predict the current structure over relatively short periods (two or three tidal cycles).

On the basis of the above conclusions, it may be necessary to monitor current information on the AUTEC Weapons Range prior to, during, and after tracking experiments in order that the dynamic oceanographic environment can be correlated with tracking of the test vehicles. However, better measurements are needed before a definite conclusion is made.

RECENT MEASUREMENTS IN AUTEC

Since the AUTEC Weapons Range will depend on a bottom-mounted system which must be compatible with the oceanic environment, bottom current information is necessary in order to facilitate the engineering design for the bottom-mounted system.

To this end bottom current measurements were made over a two-week period during March 1964. The measurements were made by NAVOCEANO at the request of NAV UNDERWATER ORDSTA, using self-recording Richardson-type current meters. Measurements were made at 2, 3, and 10 meters above the bottom and at a number of other depths. Measurements were concentrated in the launch area, re-entry area, and along a line connecting the centers of these two areas. (See figure 17.) Data were recorded on 16mm film in a gray binary code. The film is being machine read for subsequent analysis. Table 8 is a summary of recent current measurements and is included in order to detail each array. Use table 8 with figure 17.

Table 8. Summary of Recent Current Measurements in TOTO

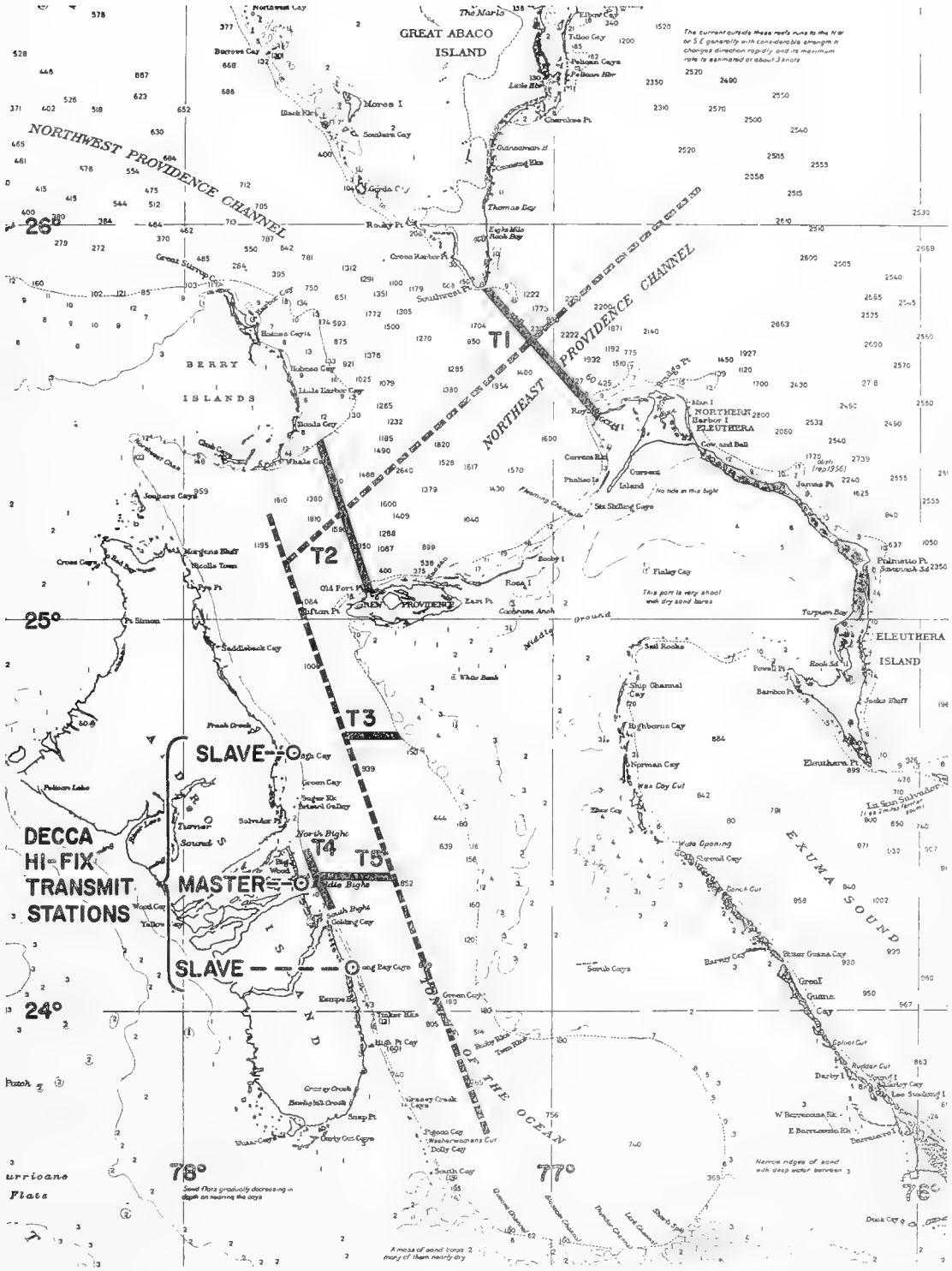
Array Station	Location	Water Depth (meters)	Time In	Time Out	Recording Time	No. of Current Meters	Current Meter Depth (meters)	Sampling Interval (min)	Remarks
A	24°25.5'N 77°33.0'W	1554	1920 on 3/13/64	---	---	7	75 225 664 1178 1543 1551 1553	20 20 20 20 20 20 5	Array lost. Retrieved mine case and Braincon buoy.
B	23°54.6'N 77°22.0'W	1280	1051 on 3/14/64	1620 on 3/21/64	173:29	7	75 225 664 1178 1269.3 1277 1278.5	20 20 20 20 20 20 5	Mine case imploded.
C	23°57.0'N 77°22.8'W	1335	1406 on 3/14/64	1750 on 3/16/64	51:44	3	1324.3 1332.0 1333.5	1 1 1	
D	24°23.3'N 77°31.8'W	1525	1750 on 3/14/64	0215 on 3/17/64	58:25	3	1514.3 1522.0 1523.5	1 1 1	Array retrieved - 24°23.9'N and 77°29.2'W.
C_1	23°59.5'N 77°23.9'W	1372	2305 on 3/16/64	0555 on 3/19/64	54:50	3	1361.3 1369.0 1370.5	1 1 1	
D_1	24°20.9'N 77°31.4'W	1505.5	0845 on 3/17/64	---	---	3	1494.8 1502.5 1504.0	1 1 1	Array lost. Retrieved mine case and Braincon buoy.
C_2	24°01.8'N 77°24.2'W	1335	1120 on 3/19/64	1335 on 3/21/64	50:15	3	1324.3 1332.0 1333.5	1 1 1	Array retrieved - 23°59.8'N and 77°25.0'W
A Modified	24°25.7'N 77°33.2'W	1554	0120 on 3/22/64	1455 on 3/30/64	205:35	4	1543.3 1548.7 1551.0 1552.5	20 20 20 20	
B Modified	23°54.5'N 77°20.0'W	1280	2050 on 3/21/64	0557 on 3/30/64	201:07	3	1269.3 1277.6 1278.5	20 20 20	
D Modified	24°23.2'N 77°31.8'W	1525	0229 on 3/22/64	0625 on 3/24/64	51.56	3	1514.3 1522.0 1523.5	1 1 1	Two meters lost during retrieval.
D_2 Modified	24°18.4'N 77°30.4'W	1481	1100 on 3/24/64	1245 on 3/26/64	49:45	3	1470.3 1478.0 1479.5	1 1 1	
D_5 Modified	24°11.4'N 77°27.7'W	1431.5	1653 on 3/26/64	1053 on 3/30/64	90:00	3	1420.8 1428.0 1430.0	1 1 1	
A_1	24°25.5'N 77°33.3'W	1554	1845 on 3/30/64	1455 on 4/15/64	380:10	4	75 226 310 1402	20 20 20 20	
B_1	24°25.7'N 77°37.3'W	1280	2053 on 3/30/64	---	---	4	75 226 677 1128	20 20 20 20	Array lost. Retrieved mine case and Braincon buoy.

REFERENCES

1. NUOS Technical Memorandum No. 306, "Lagrangian Current Measurements in the Northeast Providence Channel and the Tongue of the Ocean, Bahamas, 14 February to 6 March 1963: Preliminary Report," G. S. Cook, September 1963.

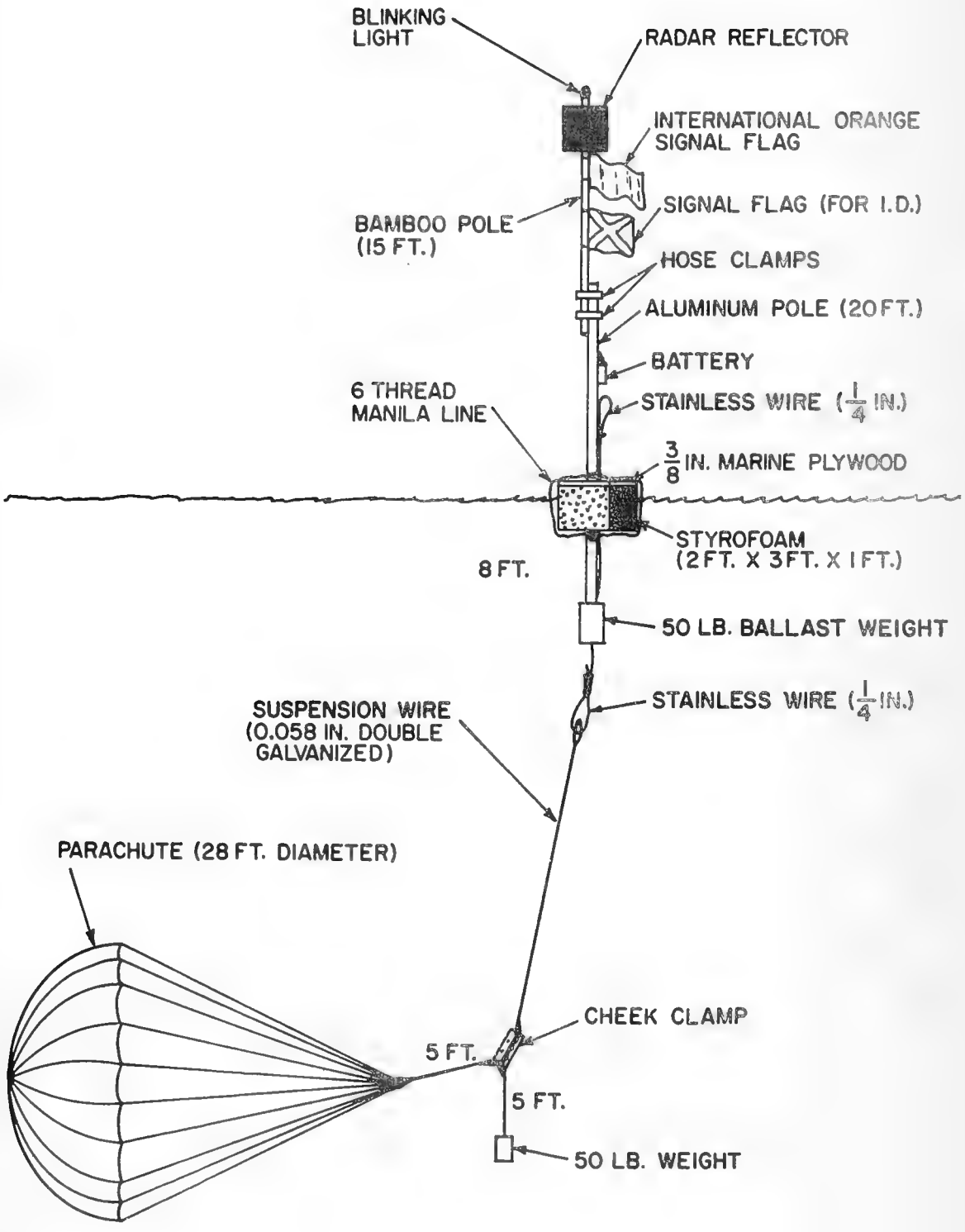
2. NUOS Technical Memorandum No. 289, "Review of the Oceanographic Environment of the Tongue of the Ocean, Bahamas; Part I: Preliminary Discussion," D. H. Shonting, May 1963.

3. NUOS Technical Memorandum No. 290, "Review of the Oceanographic Environment of the Tongue of the Ocean, Bahamas. Part II: Survey and Analysis of Ocean Current Data," G. S. Cook, October 1963.



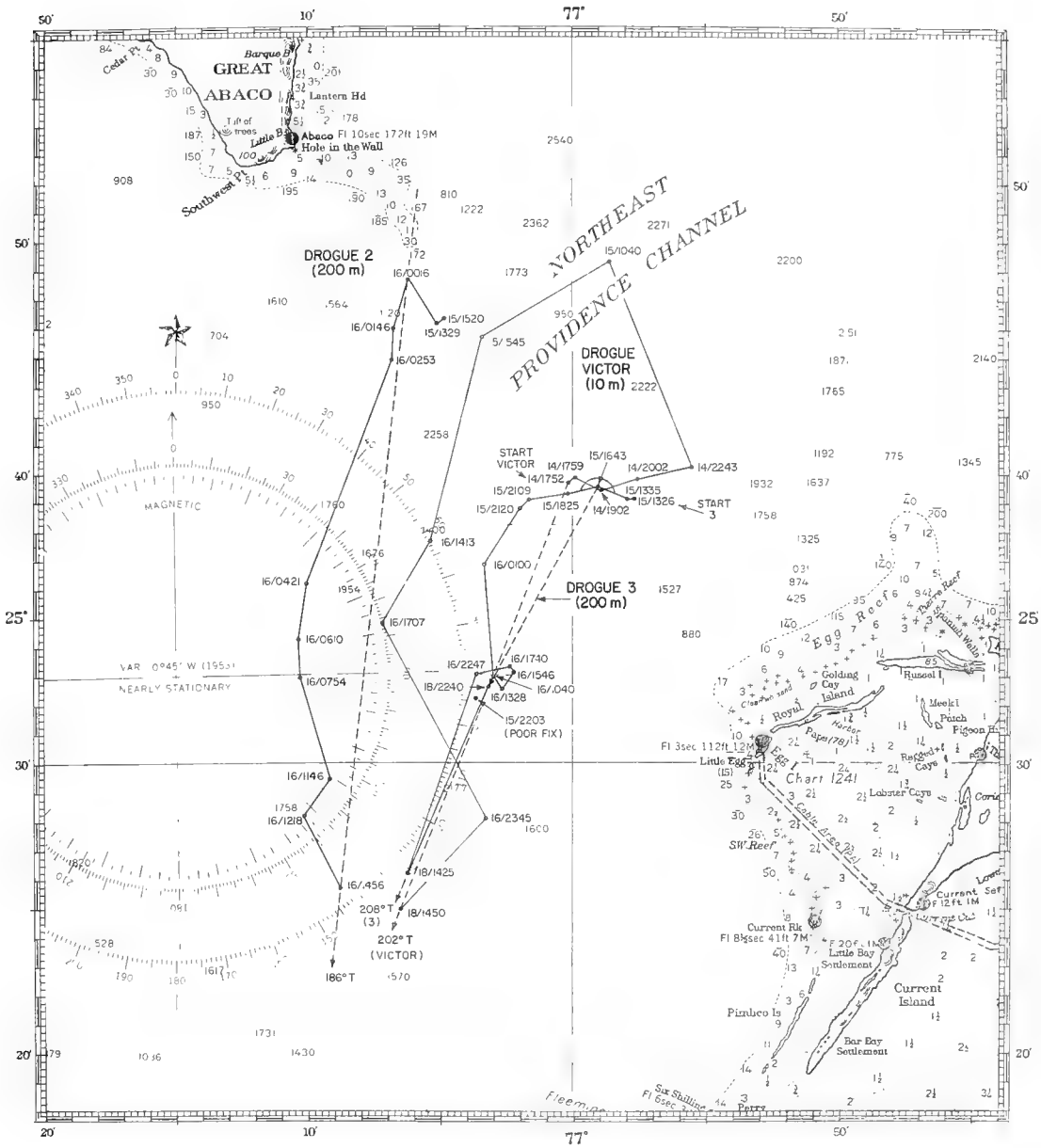
Location of Transects and Decca Hi-Fix Transmitting Stations

Figure 1



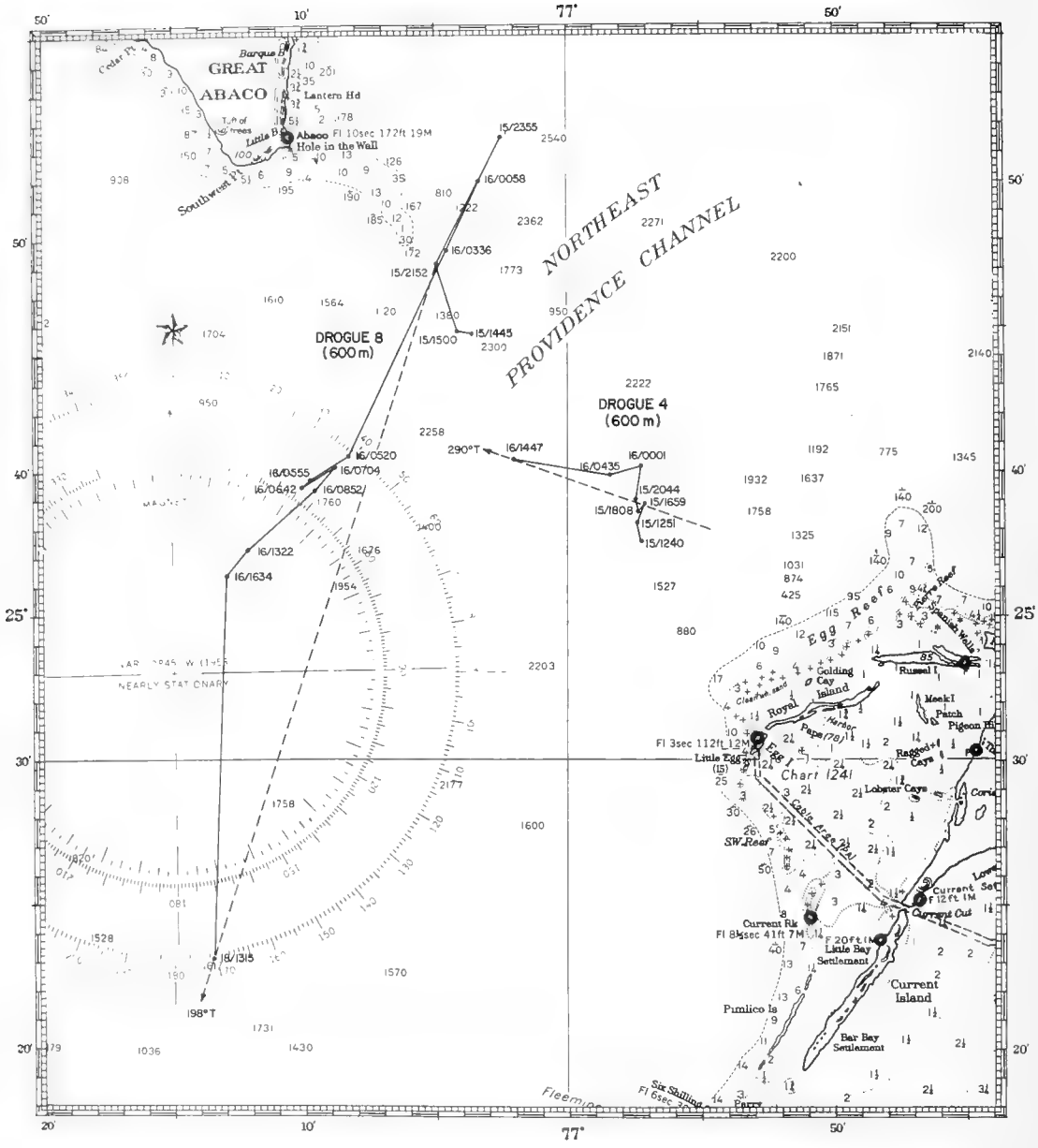
Parachute Drogue Design

FIGURE 2



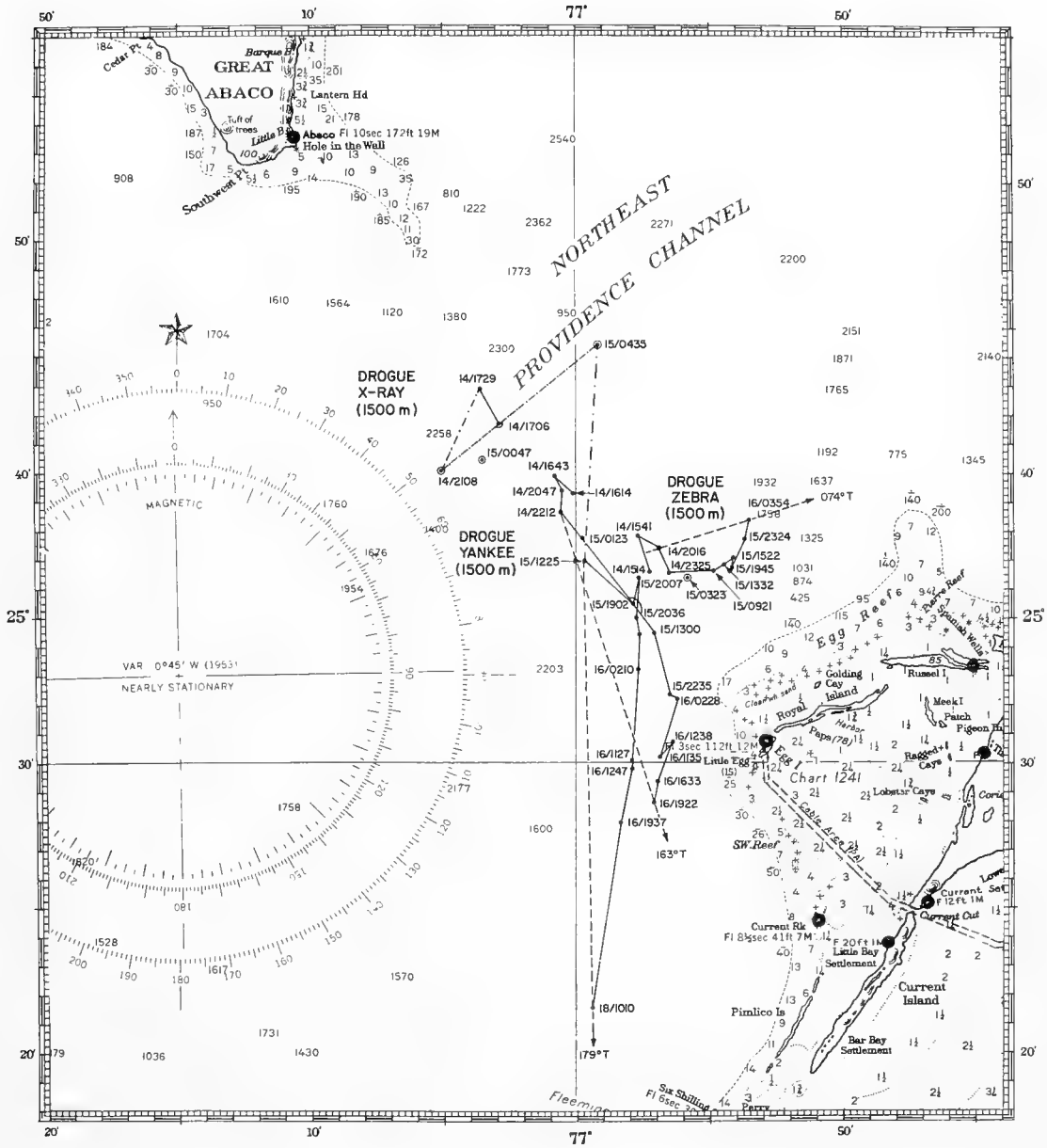
Drogue Tracks - Transect 1 (Drogues Victor, 2, and 3)

Figure 3



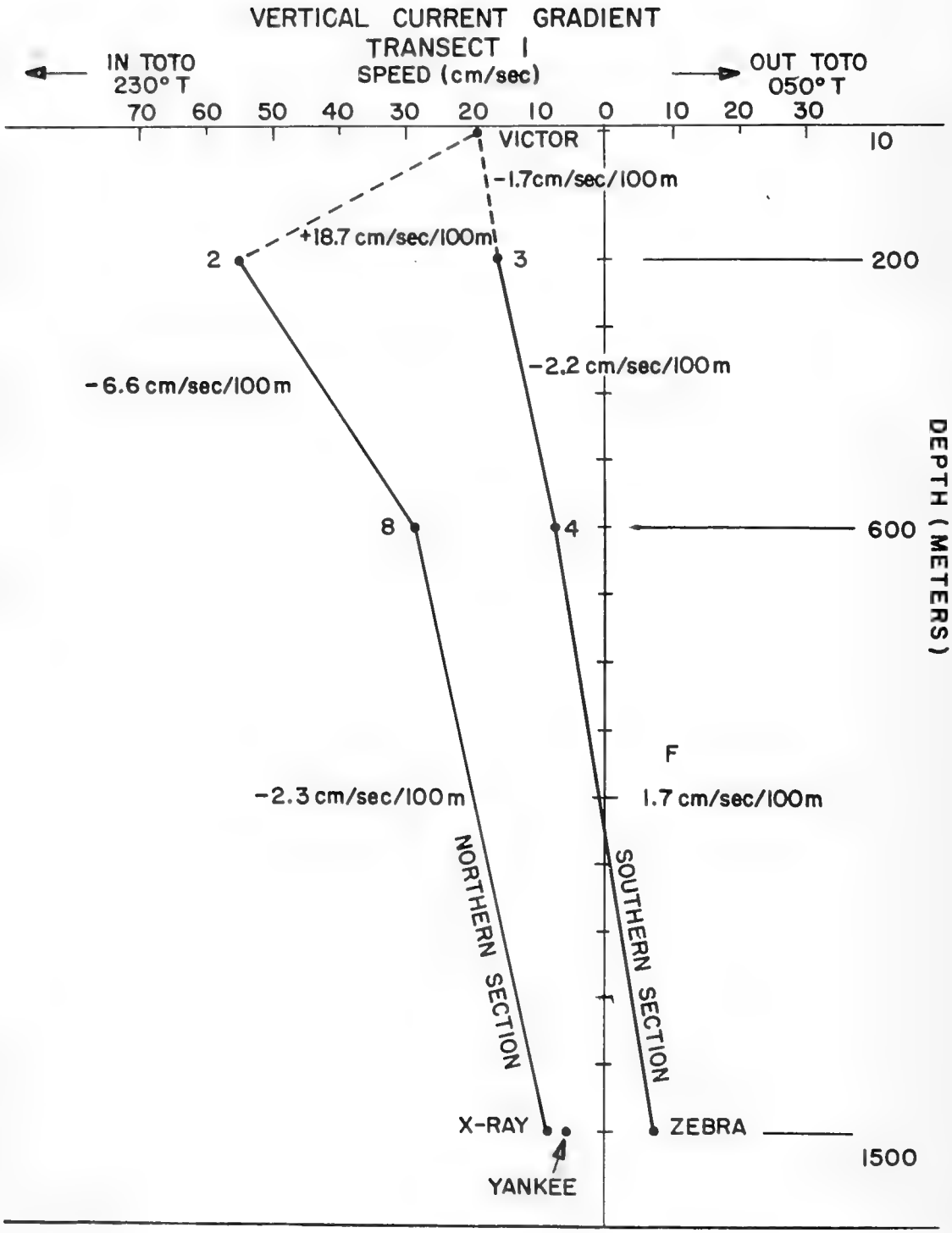
Drogue Tracks - Transect 1 (Drogues 4 and 8)

Figure 4



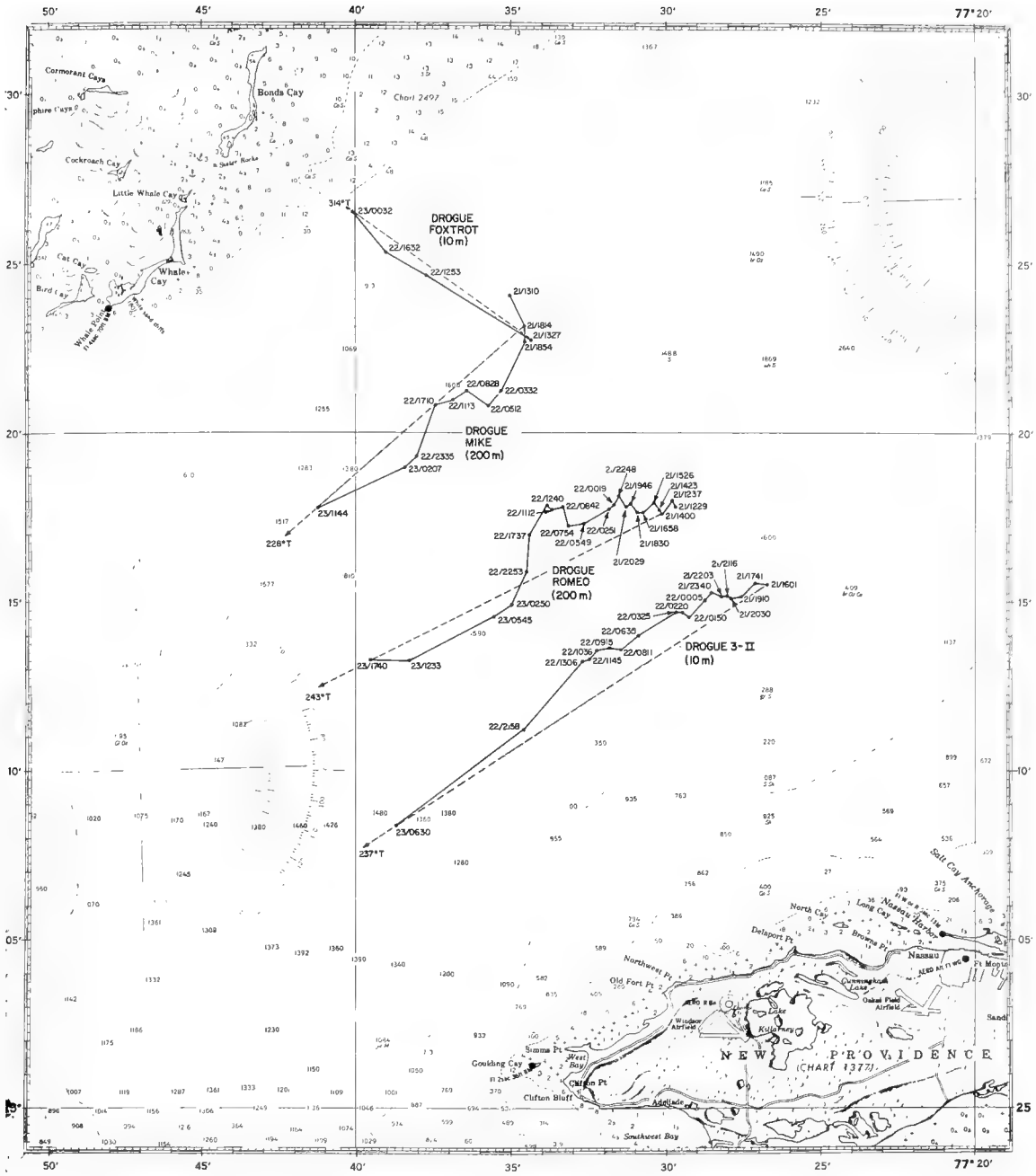
Drogue Tracks - Transect 1 (Drogues X-ray, Yankee, and Zebra)

Figure 5



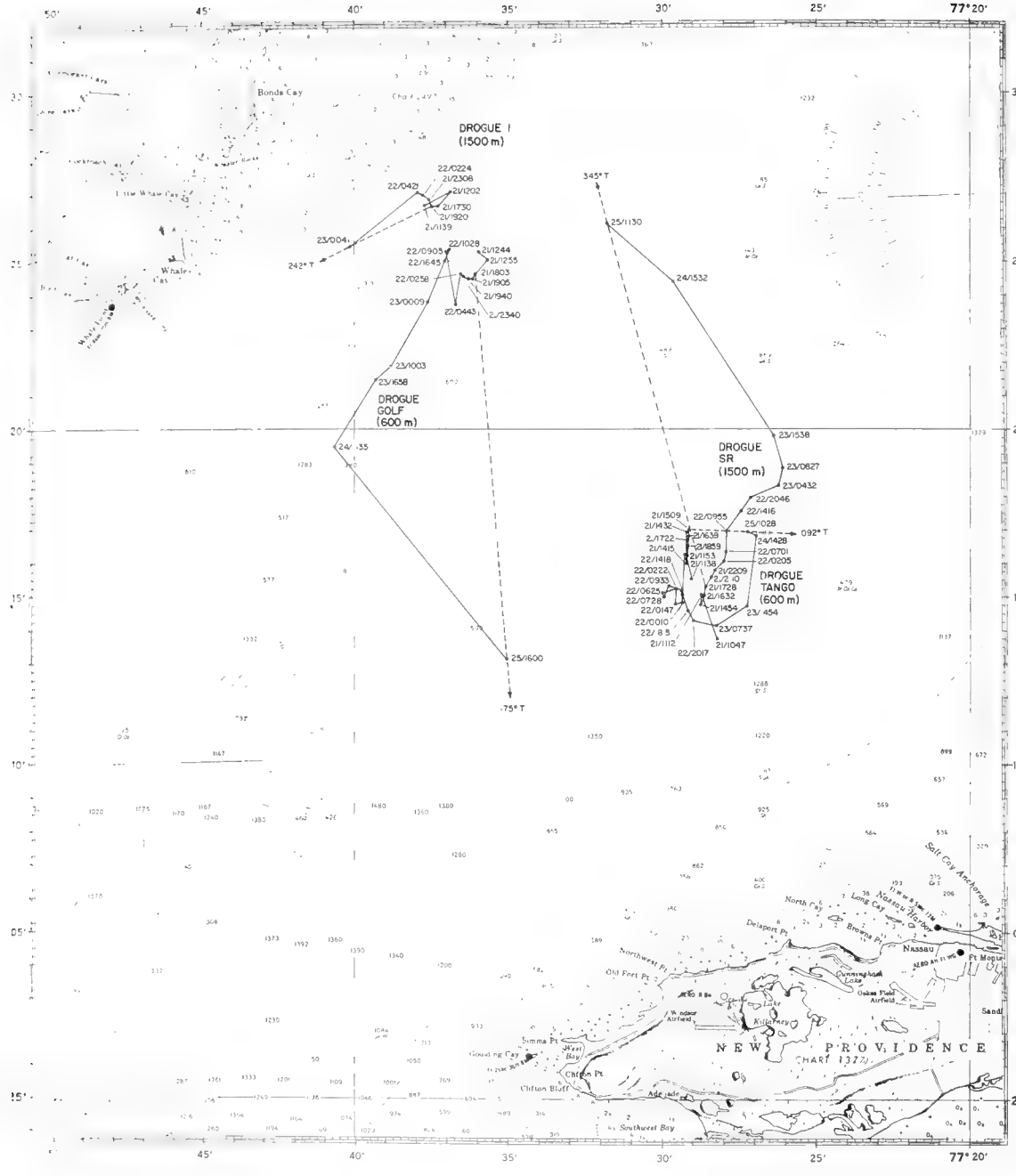
Vertical Current Gradient - Transect 1

Figure 6



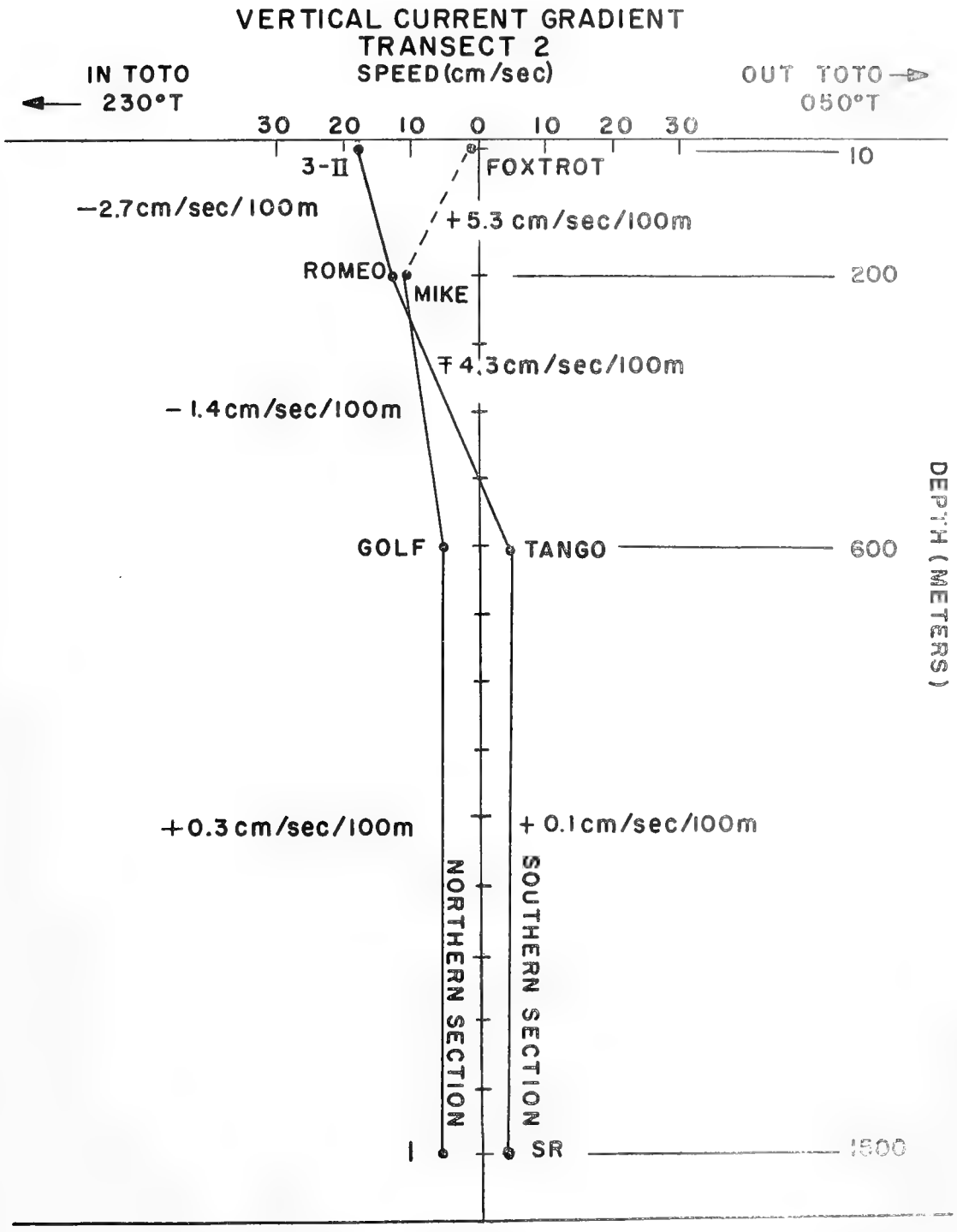
Drogue Tracks - Transect 2 (Drogues Foxtrot, 3-II, Romeo and Mike)

Figure 7



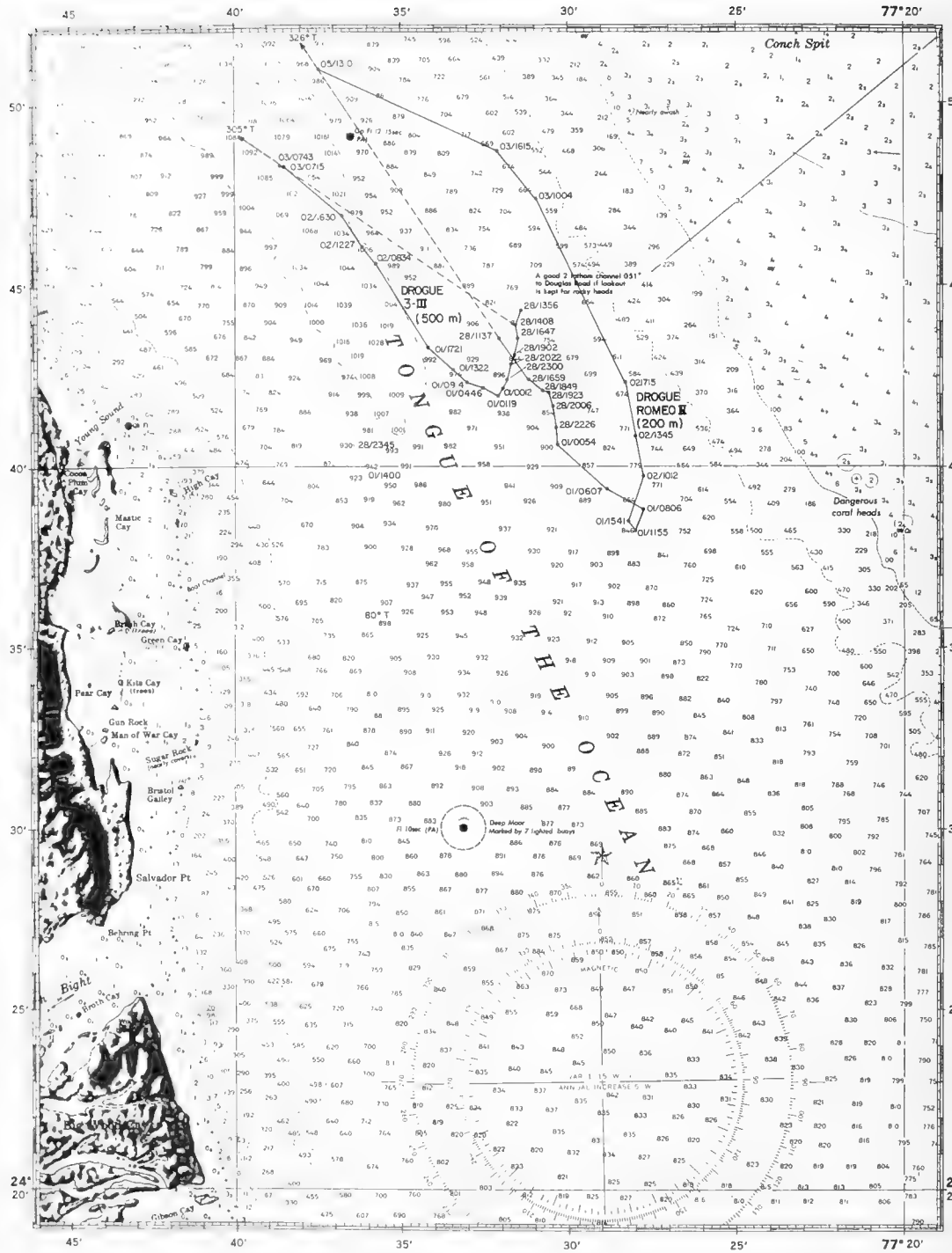
Drogue Tracks - Transect 2 (Drogues Golf, Tango, 1, and SR)

Figure 8



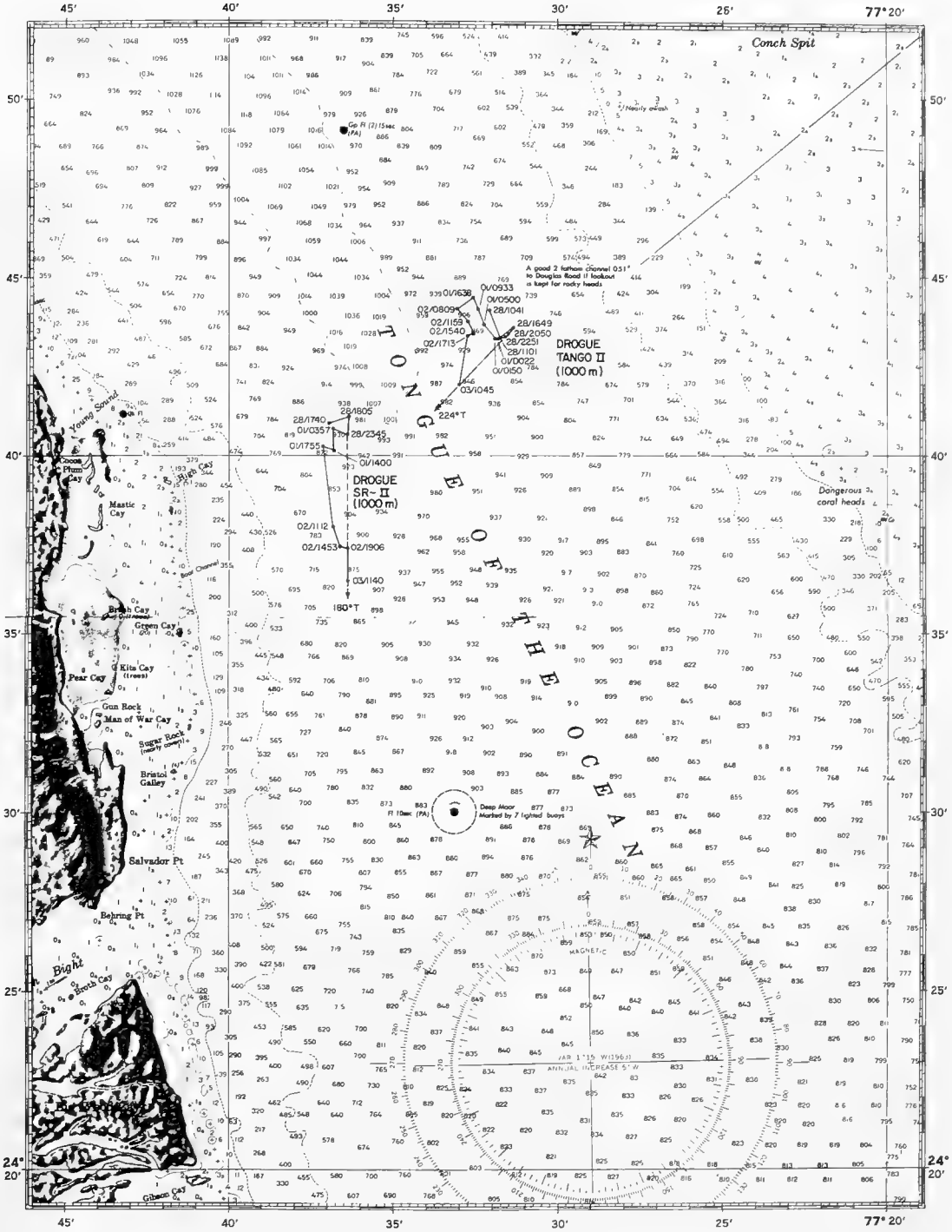
Vertical Current Gradient - Transect 2

Figure 9



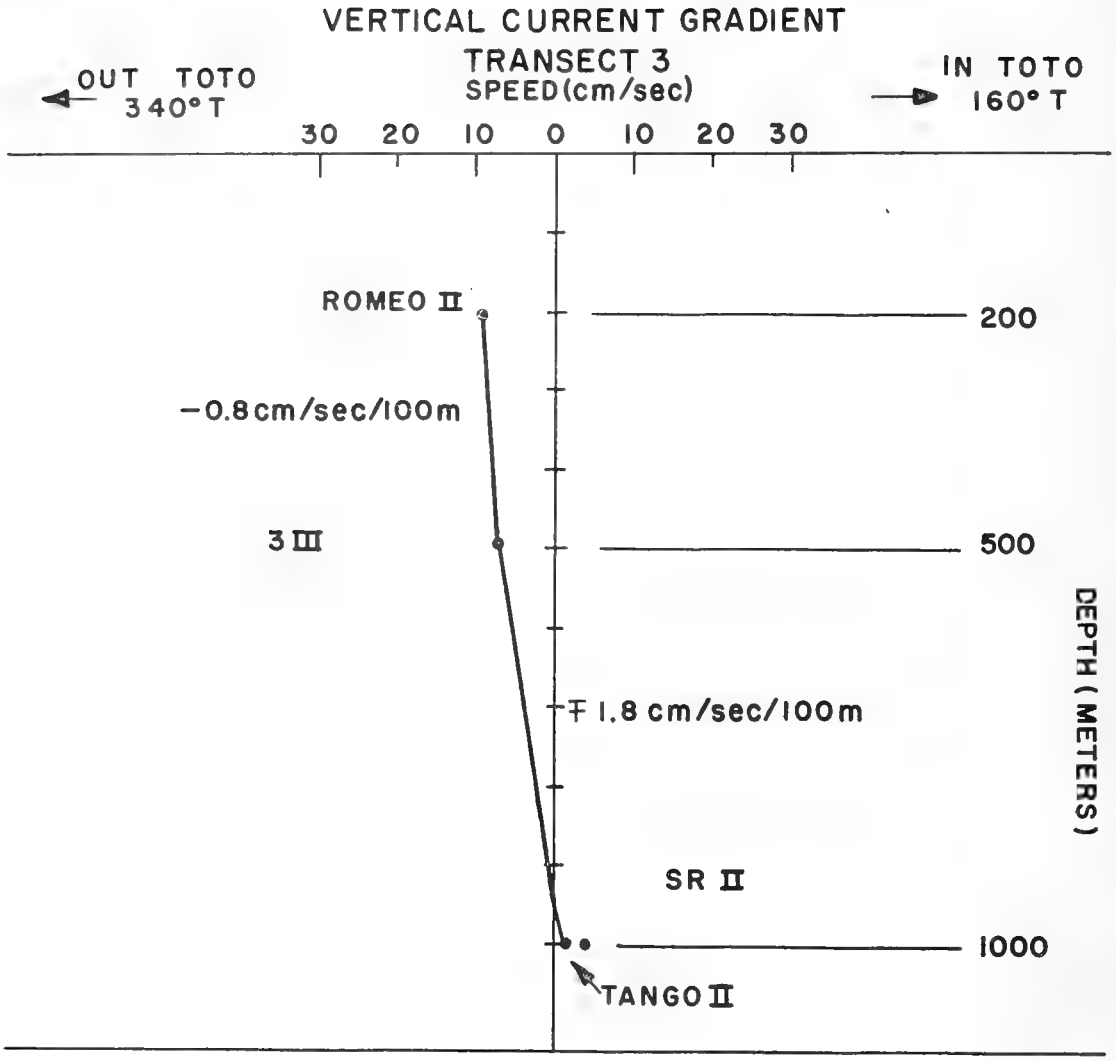
Drogue Tracks - Transect 3 (Drogues Romeo II and 3-III)

Figure 10



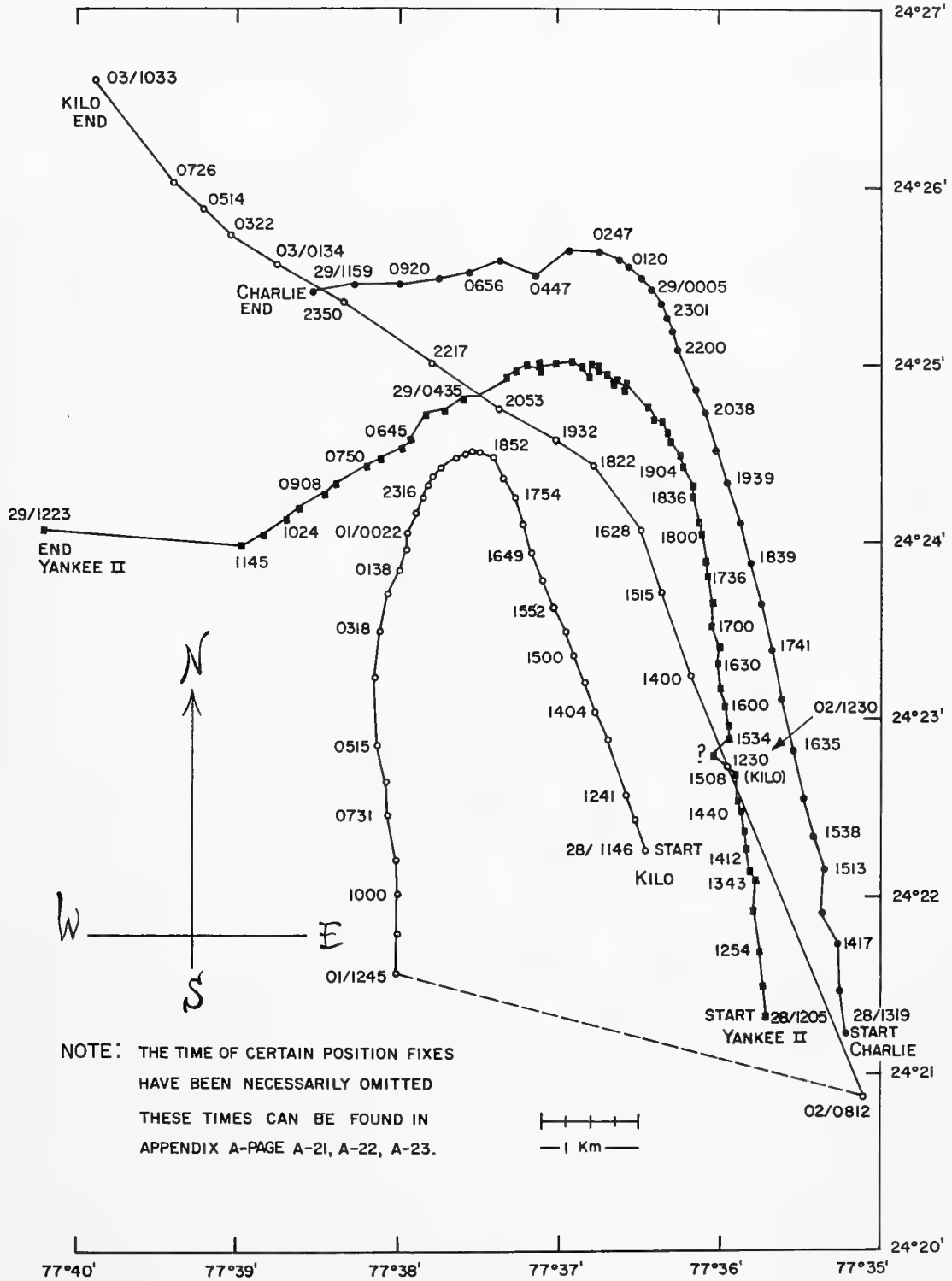
Drogue Tracks - Transect 3 (Drogues Tango II and SR-II)

Figure 11



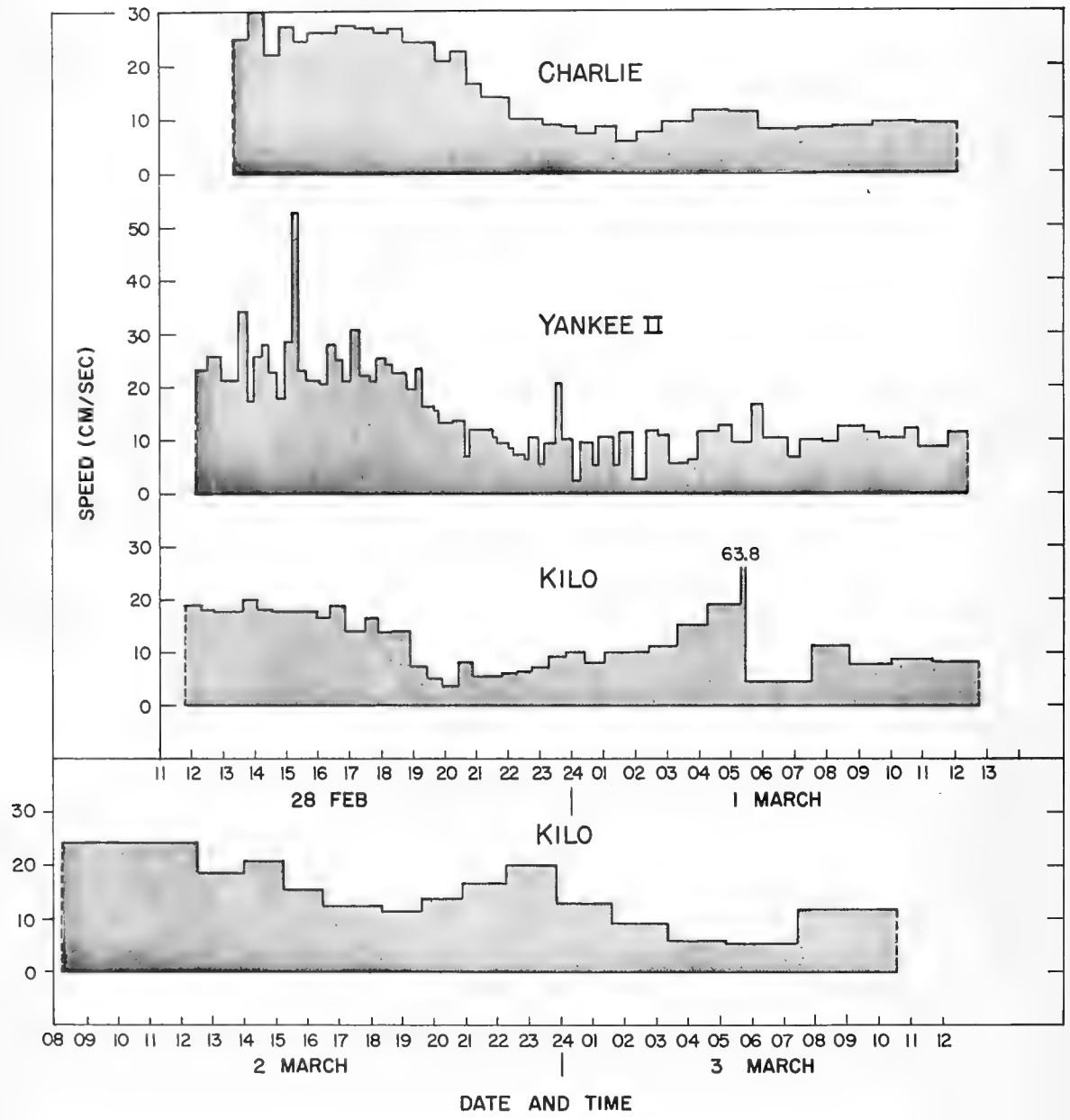
Vertical Current Gradient - Transect 3

Figure 12



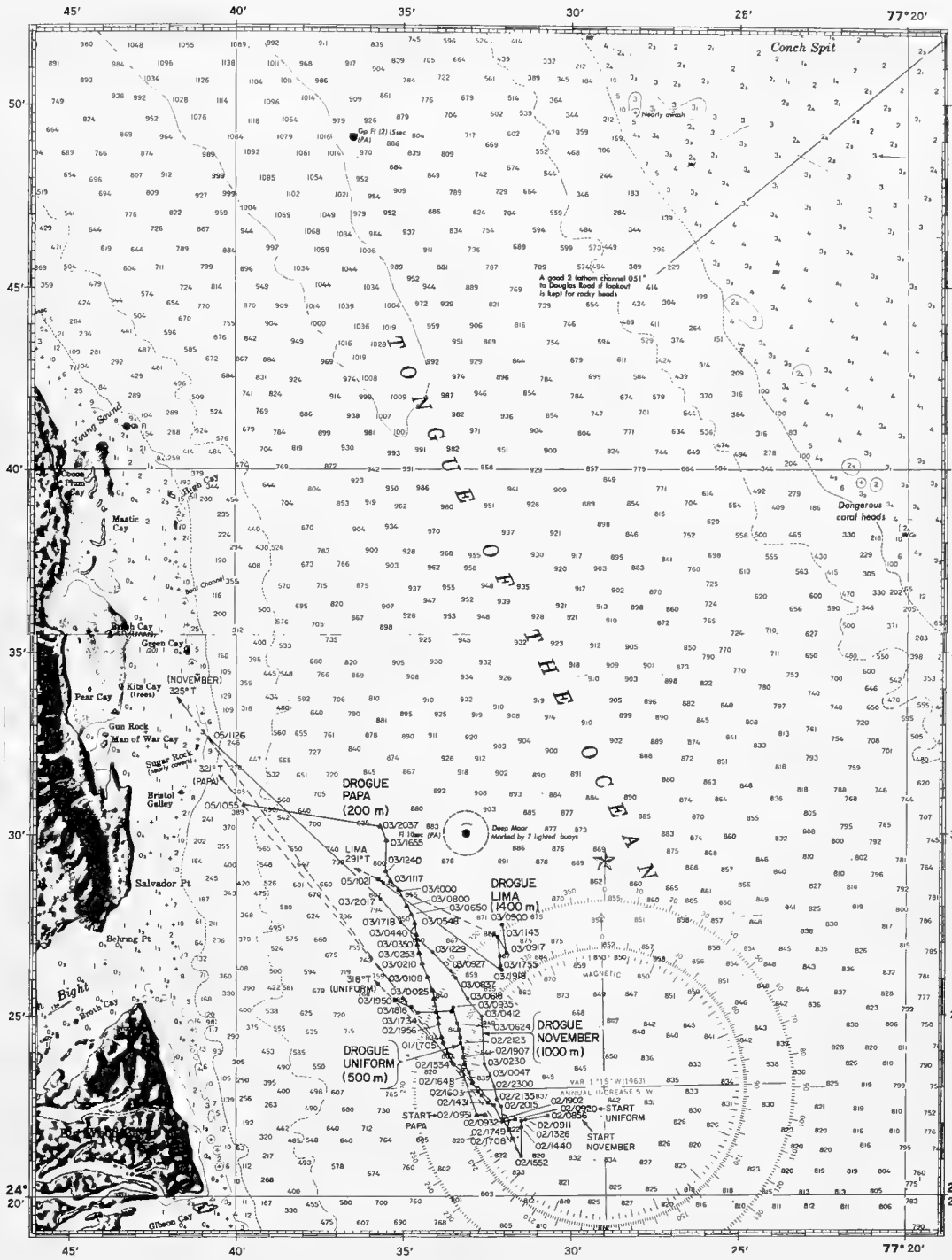
Drogue Tracks - Transect 4 (Drogues Charlie, Yankee II, and Kilo)

Figure 13



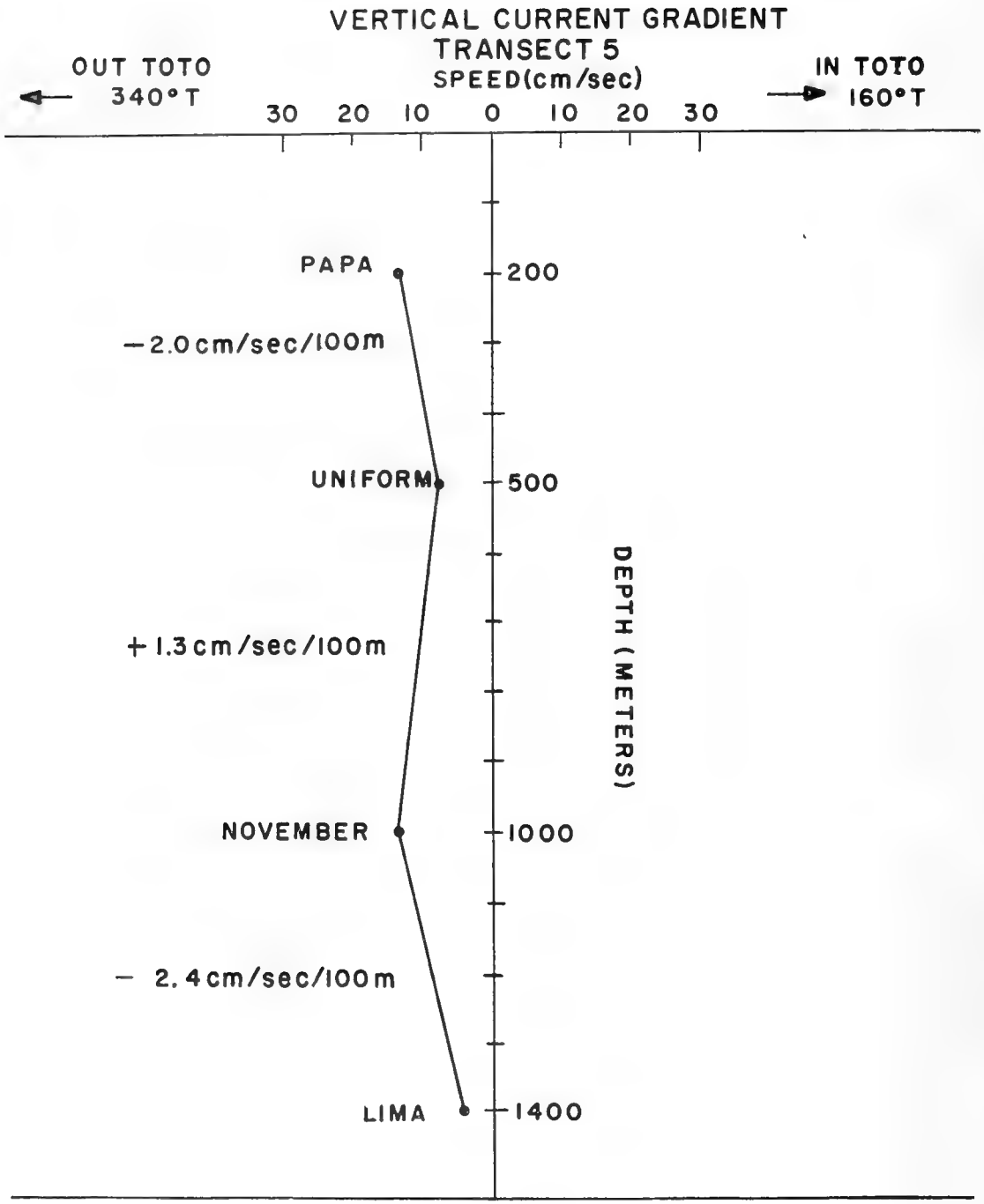
Drogue Speed vs Time - Transect 4

Figure 14



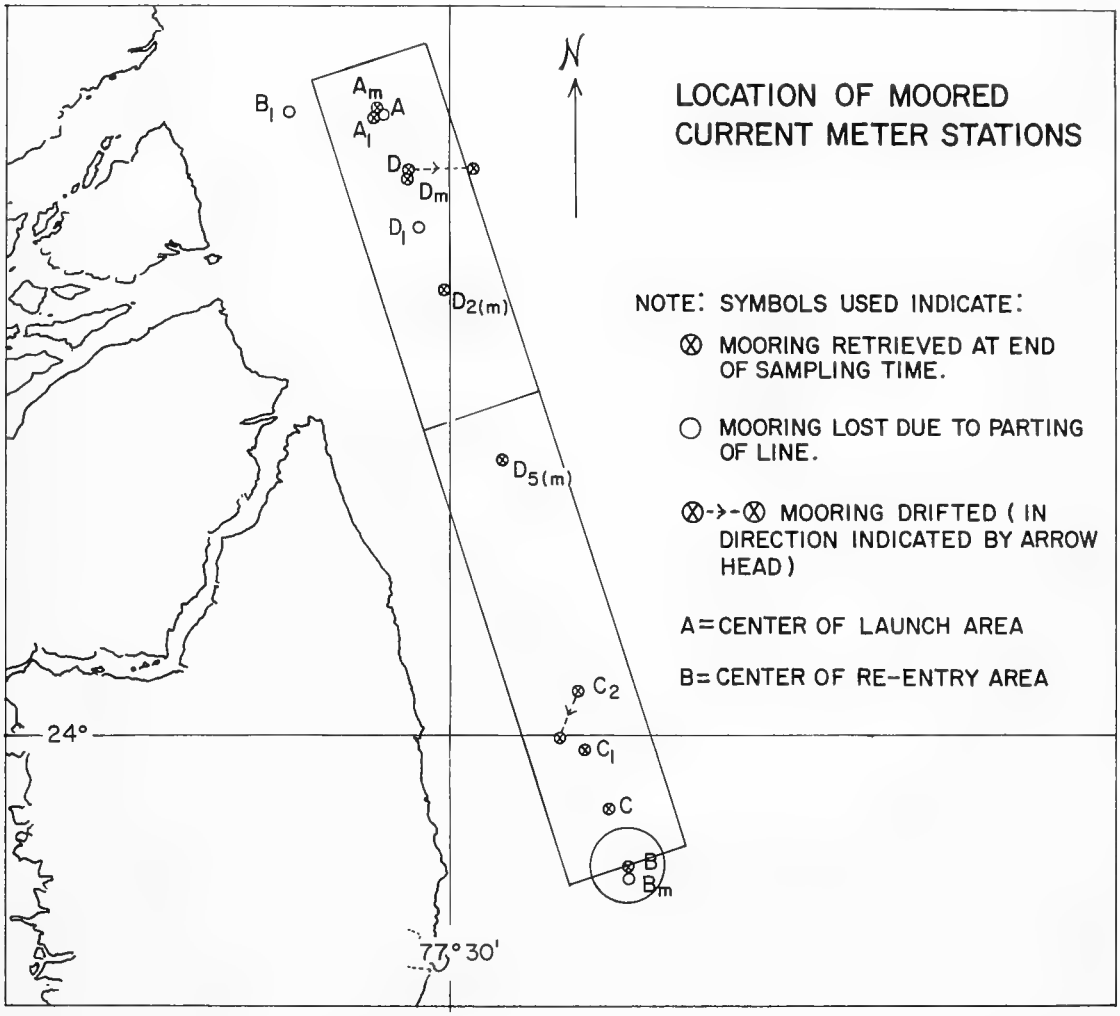
Drogue Tracks - Transect 5 (Drogues Papa, Uniform, November, and Lima)

Figure 15



Vertical Current Gradient - Transect 5

Figure 16

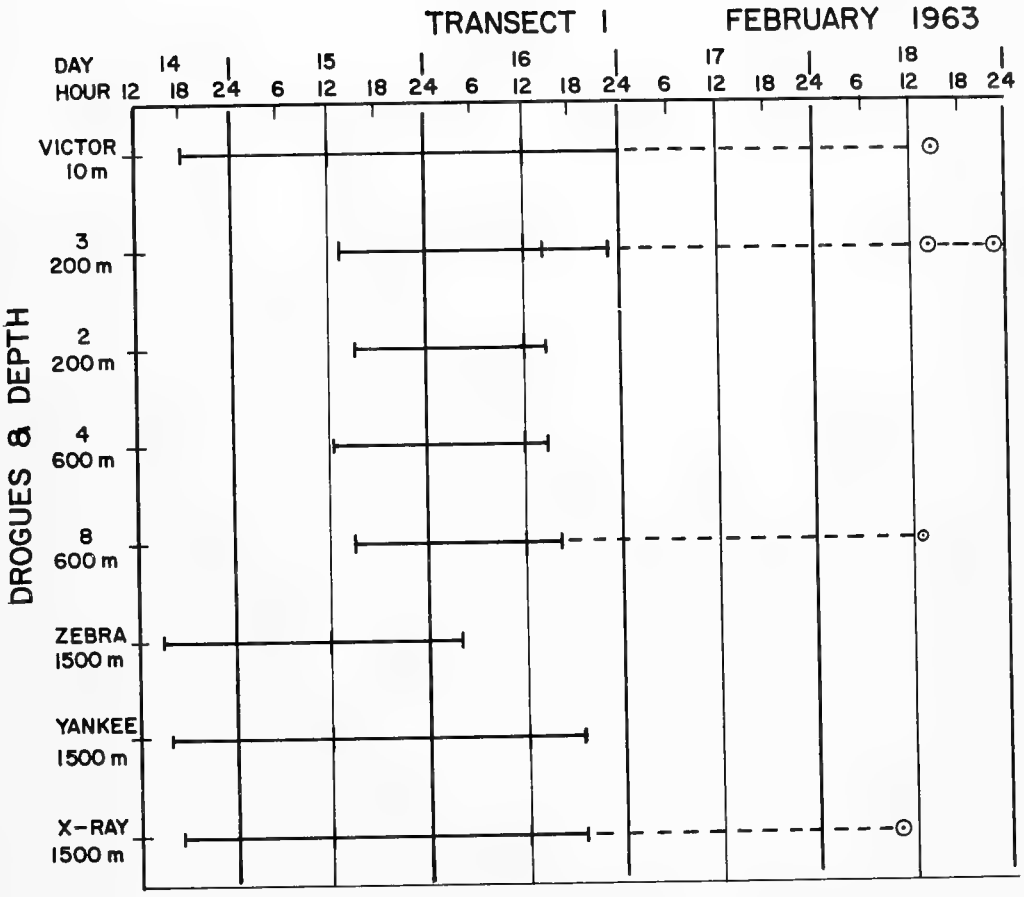


Bottom Current Measurements

Figure 17

APPENDIX A

DROGUE HISTORY AND DATA SHEETS



Drogue Travel Time - Transect 1

Figure A-1

Transect 1: DROGUE VICTOR (10 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
14 Feb	1752			Launch
	1759	48.9	118	
	1902	65.4	074	
	2002	38.1	078	
	2243	32.9	339	
15 Feb	1040	51.5	240	
	1545	17.0	195	
16 Feb	1413	57.1	211	
	1707	59.7	153	
	2345	5.7	224	
18 Feb	1450			

Average Speed	=	22.1 cm/sec
Total Travel Time	=	92.84 hours
Mean Direction	=	202°T
Displacement	=	29.2 kilometers
Total Distance	=	73.0 kilometers

Transect 1: DROGUE 3 (200 meters)

Date	Time (EST)	Time (cm/sec)	Direction (°T)	Remarks
15 Feb	1326			Launch
	1335			Settling
	1643	30.4	257	
	1825	26.3	263	
	2109	108.6	223	Questionable
	2120	33.5	212	
16 Feb	0100	20.6	175	
	1040	10.3	148	
	1328	19.6	036	
	1546	5.7	319	
	1740	12.4	259	
	2247	9.3	199	
18 Feb	1425	43.8	023	
	2240			

Average Speed = 17.5 cm/sec
Total Travel Time = 77.95 hours
Mean Direction = 208°T
Displacement = 14.6 kilometers
Total Distance = 48.5 kilometers

Transect 1: DROGUE 2 (200 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
15 Feb	1520			
				Launch
	1529			
				Settling
16 Feb	0016			
		62.3	196	
	0146			
		44.8	183	
	0253			
		288.8	201	Questionable
	0421			
		53.0	189	
	0610			
		38.1	178	
	0754			
		47.9	164	
	1146			
		153.4	216	Questionable
	1218			
		54.0	153	
	1456			

Average Speed	=	77.7 cm/sec
Total Travel Time	=	14.67 hours
Mean Direction	=	186°T
Displacement	=	39.0 kilometers
Total Distance	=	41.1 kilometers

Transect 1: DROGUE 4 (690 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
15 Feb	1240			Launch
	1251			Settling
	1659	11.3	226	
	1808	7.7	345	
	2044	18.0	010	
16 Feb	0001	12.9	255	
	0435	17.0	280	
	1447			

Average Speed	=	14.9 cm/sec
Total Travel Time	=	21.8 hours
Mean Direction	=	290°T
Displacement	=	8.9 kilometers
Total Distance	=	11.7 kilometers

Transect 1: DROGUE 8 (600 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
15 Feb	1445			
				Launch
	1500			
				Settling
	2152			
		134.4	026	Questionable
	2355			
		90.6	206	
16 Feb	0058			
		56.1	205	
	0336			
		252.7	205	Questionable
	0520			(Not used)
		150.8	237	
	0555			
		23.2	228	
	0642			
		187.9	059	Questionable
	0704			
		31.9	221	
	0852			
		38.1	228	
	1322			
		20.1	219	
	1634			
		16.5	182	
18 Feb	1315			

Average Speed	=	34.0 cm/sec
Total Travel Time	=	63.41 hours
Mean Direction	=	198°T
Displacement	=	46.4 kilometers
Total Distance	=	77.3 kilometers

Transect 1: DROGUE ZEBRA (1500 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
14 Feb	1514			Launch
	1541			Settling
	2016	14.4	155	
	2325	7.7	089	
15 Feb	0921	5.7	061	
	1332	10.3	058	
	1522	3.1	186	
	1945	15.4	024	
	2324	7.2	013	
16 Feb	0354			

Average Speed	=	8.2 cm/sec
Total Travel Time	=	31.97 hours
Mean Direction	=	074°T
Displacement	=	5.9 kilometers
Total Distance	=	9.6 kilometers

Transect 1: DROGUE YANKEE (1500 meters)

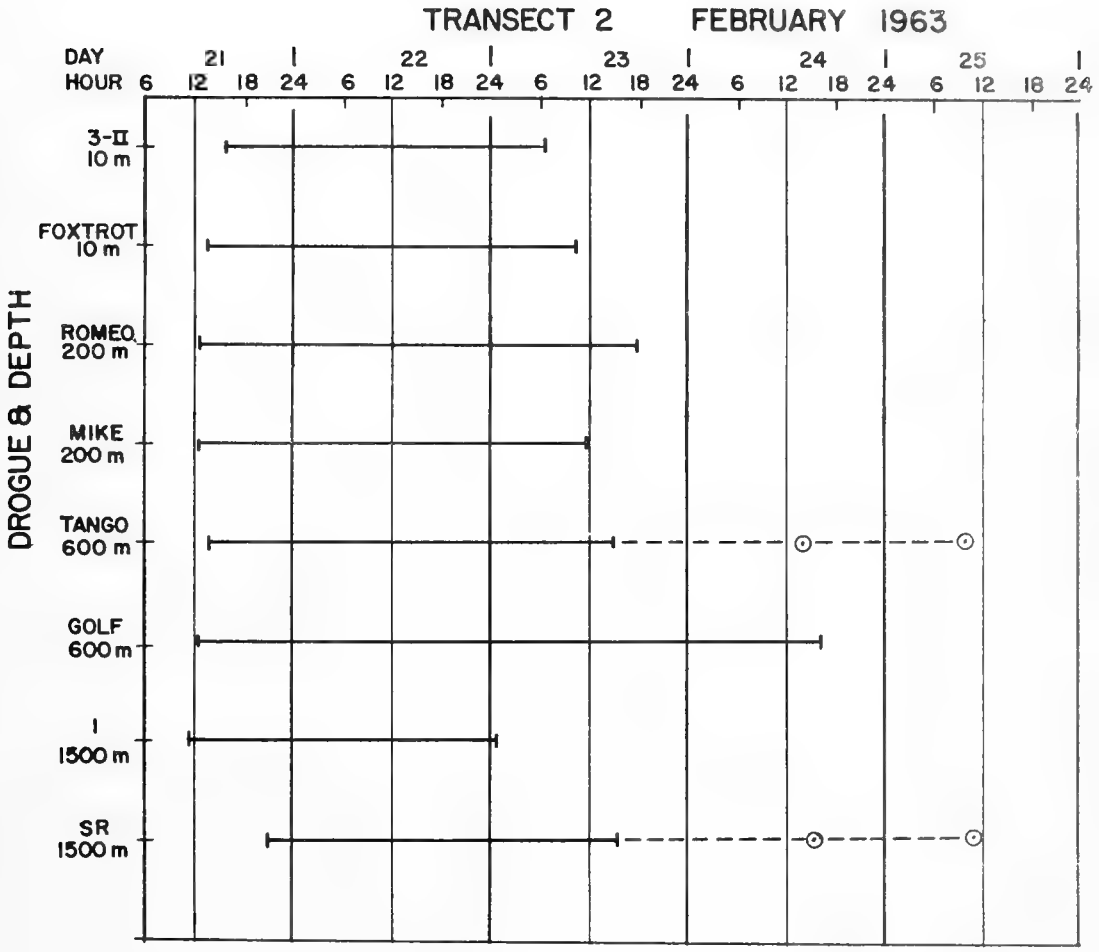
Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
14 Feb	1614			
				Launch
	1643			
				Settling
	2047			
				Settling
	2212			
		18.5	152	
15 Feb	0123			
		18.5	154	
	1300			
		11.8	176	
	2235			
		4.6	115	
16 Feb	0228			
		11.8	197	
	1135			
		30.4	040	
	1238			
		19.0	200	
	1633			
		13.4	191	
	1922			

Average Speed	=	14.4 cm/sec
Total Travel Time	=	45.0 hours
Mean Direction	=	163°T
Displacement	=	19.4 kilometers
Total Distance	=	23.6 kilometers

Transect 1: DROGUE X-RAY (1500 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
14 Feb	1706			
				Launch
	1729			
				Settling
	2108			
		-	-	
15 Feb	0323			
		-	-	
	0435			
		-	-	
	1225			
		18.0	133	
	1902			
		45.3	015	
	2007			
		146.7	185	Questionable
	2036			
		19.6	171	
	2215			
		16.0	182	
16 Feb	0210			
		17.5	184	
	1127			
		9.8	182	
	1247			
		14.4	192	
	1937			
		8.8	189	
18 Feb	1010			

Average Speed	=	13.4 cm/sec
Total Travel Time	=	69.74 hours
Mean Direction	=	179°T
Displacement	=	28.3 kilometers
Total Distance	=	33.6 kilometers



Drogue Travel Time - Transect 2

Figure A-2

Transect 2: DROGUE FOXTROT (10 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1338			
		8.2	302	
22 Feb	1253			
		19.6	300	
	1632			
		10.3	321	
23 Feb	0032			
		20.1	329	
	1039			

Average Speed	=	12.4 cm/sec
Total Travel Time	=	45.02 hours
Mean Direction	=	314°T
Displacement	=	18.9 kilometers
Total Distance	=	19.6 kilometers

Transect 2: DROGUE 3-II (10 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1601			
		11.3	281	
	1741			
		20.6	225	
	1910			
		11.8	259	
	2030			
		8.8	303	
	2116			
		12.4	265	
	2203			
		9.8	294	
	2340			
		34.5	220	
22 Feb	0005			
		21.1	220	
	0150			
		25.7	310	
	0220			
		9.3	270	
	0325			
		21.6	237	
	0635			
		21.1	231	
	0811			
		17.5	278	
	0915			
		15.4	257	
	1036			
		14.9	221	
	1145			
		8.2	252	
	1306			
		16.0	220	
	2158			
		28.8	233	
23 Feb	0630			

Average Speed	=	18.5 cm/sec
Total Travel Time	=	38.31 hours
Mean Direction	=	237°T
Displacement	=	24.3 kilometers
Total Distance	=	25.9 kilometers

Transect 2: DROGUE ROMEO (200 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1229			Launch
	1237			Settling
	1400	20.1	326	
	1423	12.4	326	
	1526	13.9	226	
	1658	6.7	264	
	1830	12.4	327	
	1946	14.9	226	
	2029	8.8	329	
	2248	8.2	208	
22 Feb	0019	5.1	225	
	0251	15.4	240	
	0549	12.4	260	
	0754	38.6	346	
	0842	7.7	255	
	1112	7.2	312	
	1240	10.8	210	
	1737	10.8	184	
	2253	13.9	204	
23 Feb	0250	11.8	236	
	0545	21.6	242	
	1233	11.8	271	
	1740			

Average Speed = 13.4 cm/sec
Total Travel Time = 53.18 hours
Mean Direction = 243°T

Displacement = 18.0 kilometers
Total Distance = 25.2 kilometers

Transect 2: DROGUE MIKE (200 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1258			Launch
	1310			Settling
	1814	32.9	180	
	1854	9.8	205	
22 Feb	0332	18.0	218	
	0512	12.4	306	
	0828	9.3	235	
	1113	5.7	251	
	1710	12.9	198	
	2335	10.3	227	
23 Feb	0207	14.9	244	
	1144			

Average Speed	=	11.3 cm/sec
Total Travel Time	=	46.60 hours
Mean Direction	=	228°T
Displacement	=	15.1 kilometers
Total Distance	=	19.4 kilometers

Transect 2: DROGUE GOLF (600 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1244			
				Launch
	1255			
				Settling
	1803			
		8.8	211	
	1905			
		9.8	267	
	1940			
		3.1	294	
	2340			
		11.0	304	
22 Feb	0258			
		25.2	190	
	0443			
		18.0	350	
	0905			
		3.1	035	
	1028			
		2.6	195	
	1645			
		9.3	203	
23 Feb	0009			
		11.3	210	
	1003			
		4.1	228	
	1658			
		6.7	212	
24 Feb	1135			
		14.9	141	
	1600			

Average Speed	=	9.8 cm/sec
Total Travel Time	=	99.30 hours
Mean Direction	=	175°T
Displacement	=	21.5 kilometers
Total Distance	=	35.3 kilometers

Transect 2: DROGUE TANGO (600 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1415			
				Launch
	1432			
				Settling
	1509			
				Settling
	1639			
		9.3	194	
	1722			
		6.2	180	
	1859			
		11.8	189	
	2016			
		18.5	186	
	2328			
		17.5	180	
22 Feb	0010			
		7.7	248	
	0147			
		44.3	005	
	0222			
		5.1	248	
	0625			
		5.1	182	
	0728			
		8.8	025	
	0933			
		4.1	110	
	1418			
		7.7	161	
	1815			
		9.8	150	
	2017			
		3.1	103	
23 Feb	0737			
		8.2	058	
	1454			
		4.6	008	
24 Feb	1428			
		0.5	293	
25 Feb	1028			

Average Speed	=	5.7 cm/sec
Total Travel Time	=	92.21 hours
Mean Direction	=	092°T
Displacement	=	3.3 kilometers
Total Distance	=	19.3 kilometers

Transect 2: DROGUE 1 (1500 meters)

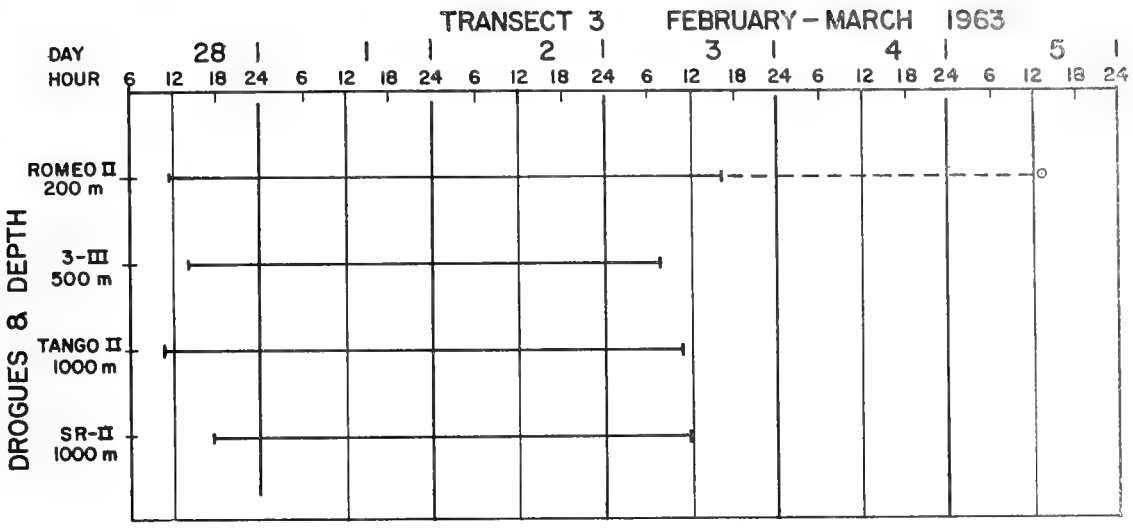
Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	1139			
				Launch
	1202			
				Settling
	1730			
		5.1	267	
	1920			
		3.1	338	
	2308			
		4.1	303	
22 Feb	0224			
		4.1	297	
	0421			
		6.2	230	
23 Feb	0041			

Average Speed	=	6.2 cm/sec
Total Travel Time	=	37.10 hours
Mean Direction	=	242°T
Displacement	=	5.0 kilometers
Total Distance	=	8.8 kilometers

Transect 2: DROGUE SR (1500 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
21 Feb	2110			
		1.5	030	
	2209			
		5.1	044	
22 Feb	0205			
		2.6	014	
	0701			
		11.3	000	
	0955			
		8.7	035	
	1416			
		4.1	036	
	2046			
		6.2	066	
23 Feb	0432			
		6.7	012	
	0827			
		6.7	345	
	1538			
		11.3	327	
24 Feb	1532			
		6.7	311	
25 Feb	1130			

Average Speed	=	7.7 cm/sec
Total Travel Time	=	88.10 hours
Mean Direction	=	345°T
Displacement	=	20.9 kilometers
Total Distance	=	24.5 kilometers



Drogue Travel Time - Transect 3

Figure A-3

Transect 3: DROGUE ROMEO II (200 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
28 Feb	1137			Launch
	1659	14.4	134	
	1849	14.4	090	
	1923	27.3	162	
	2006	12.4	174	
	2226	9.8	166	
1 Mar	0054	18.0	133	
	0607	29.3	119	
	0806	8.2	200	
	1155	3.6	330	
	1541	3.6	018	
2 Mar	1012	16.5	350	
	1345	22.1	350	
	1715	17.5	334	
3 Mar	1004	13.9	320	
	1615	6.2	294	
5 Mar	1310			

Average Speed	=	9.8 cm/sec
Total Travel Time	=	116.20 hours
Mean Direction	=	326°T
Displacement	=	19.2 kilometers
Total Distance	=	41.9 kilometers

Transect 3: DROGUE 3-III (500 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
28 Feb	1356			Launch
	1409	6.7	167	
	1647	10.3	198	
	1902	11.8	210	
	2022	8.8	177	
	2300	11.3	230	
1 Mar	0012	11.3	210	
	0119	7.2	302	
	0446	4.6	302	
	0914	6.7	302	
	1322	11.8	315	
	1721	9.3	328	
2 Mar	0834	8.2	315	
	1227	13.4	330	
	1630	7.2	310	
3 Mar	0715	10.8	287	
	0743			

Average Speed	=	8.7 cm/sec
Total Travel Time	=	66.18 hours
Mean Direction	=	305°T
Displacement	=	14.7 kilometers
Total Distance	=	20.5 kilometers

Transect 3: DROGUE SR-II (1000 meters)

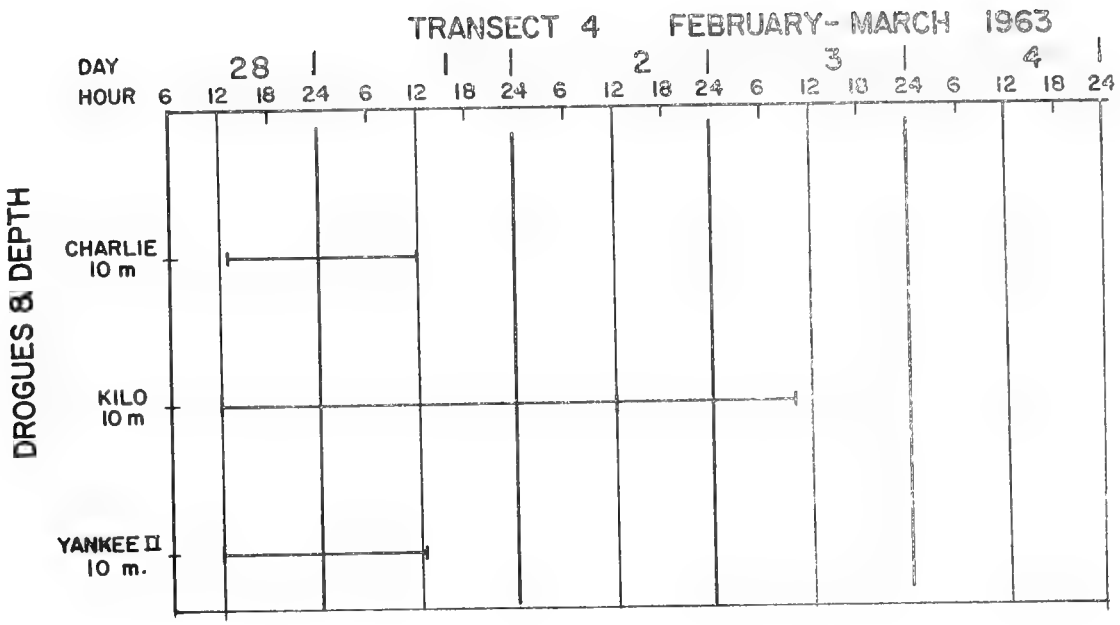
Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
28 Feb	1740			Launch
	1805			Settling
	2345	4.6	287	
1 Mar	0357	3.1	180	
	1400	4.1	286	
	1755	6.7	173	
2 Mar	1112	7.7	163	
	1453	3.1	090	
	1906	2.6	180	
3 Mar	1140			

Average Speed	=	4.1 cm/sec
Total Travel Time	=	59.92 hours
Mean Direction	=	180°T
Displacement	=	7.6 kilometers
Total Distance	=	9.7 kilometers

Transect 3: DROGUE TANGO II (1000 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
28 Feb	1041			
				Launch
	1101			
				Settling
	1649			
		3.1	217	
	2050			
		4.1	252	
1 Mar	0150			
		8.8	320	
	0500			
		5.1	339	
	0933			
		2.6	339	
	1638			
		1.5	235	
2 Mar	0809			
		5.7	140	
	1159			
		5.1	145	
	1540			
		6.2	248	
	1713			
		4.1	190	
3 Mar	1045			

Average Speed	=	3.6 cm/sec
Total Travel Time	=	65.92 hours
Mean Direction	=	224°T
Displacement	=	4.1 kilometers
Total Distance	=	9.1 kilometers



Drogue Travel Time - Transect 4

Figure A-4

Transect 4: DROGUE KILO (10 meters)

Date	Time (EST)	Speed (cm/sec)
28 Feb	1146	
		19.0
	1216	
		18.1
	1241	
		17.8
	1336	
		20.0
	1404	
		18.0
	1432	
		17.8
	1500	
		17.7
	1526	
		17.2
	1552	
		16.8
	1622	
		18.7
	1649	
		14.0
	1725	
		16.4
	1754	
		13.8
	1824	
		14.0
	1852	
		7.2
	1924	
		5.0
	1953	
		3.6
	2024	
		7.1
	2050	
		5.5
	2145	
		6.1
	2217	
		6.4
	2245	
		7.2
	2316	
		9.0
	2347	
		9.9
1 Mar	0022	
		7.9
	0100	
		10.0
	0138	

Date	Time (EST)	Speed (cm/sec)
1 Mar	0138	
		10.2
	0222	
		11.2
	0318	
		15.1
	0413	
		19.0
	0515	
		63.8*
	0525	
		4.4
	0731	
		11.2
	0843	
		7.6
	1000	
		8.6
	1119	
		8.1
	1245	
		7.3
2 Mar	0812	
		24.4
	1230	
		18.6
	1400	
		20.8
	1515	
		15.4
	1628	
		12.2
	1822	
		11.3
	1932	
		13.8
	2053	
		16.6
	2217	
		19.9
	2350	
		12.9
3 Mar	0134	
		9.0
	0322	
		5.8
	0514	
		5.3
	0726	
		11.7
	1033	

*Questionable

Date	Time (EST)	Speed (cm/sec)
28 Feb	1205	
		23.3
	1230	
		25.7
	1254	
		21.2
	1327	
		34.3
	1343	
		17.2
	1355	
		25.7
	1412	
		28.0
	1424	
		22.7
	1440	
		17.7
	1452	
		28.6
	1508	
		52.9
	1517	
		23.1
	1534	
		21.4
	1545	
		21.3
	1600	
		20.5
	1615	
		28.0
	1630	
		25.2
	1641	
		21.2
	1700	
		30.8
	1714	
		22.1
	1736	
		20.9
	1747	
		25.4
	1806	
		24.3
	1815	
		22.7
	1836	

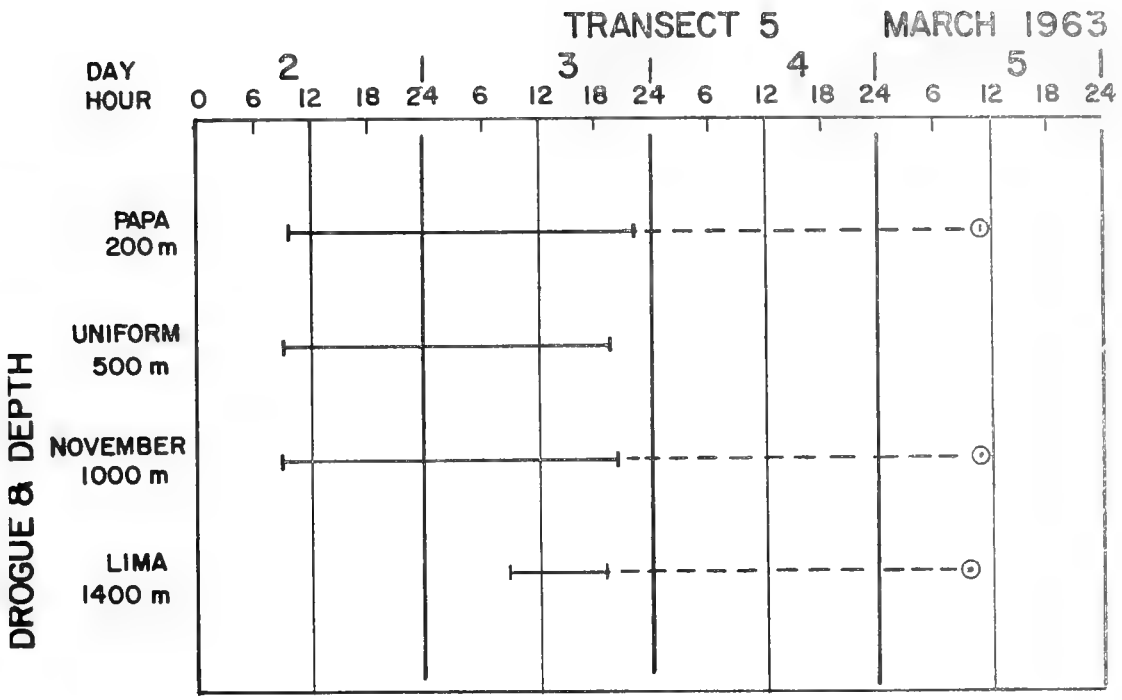
Date	Time (EST)	Speed (cm/sec)
28 Feb	1836	
		22.4
	1844	
		19.6
	1904	
		23.6
	1913	
		16.3
	1936	
		15.4
	1944	
		13.2
	2004	
		13.1
	2013	
		13.7
	2033	
		6.9
	2042	
		12.1
	2128	
		10.4
	2135	
		9.4
	2157	
		8.4
	2205	
		7.1
	2228	
		6.3
	2236	
		10.6
	2256	
		5.6
	2306	
		9.3
	2327	
		20.8
	2338	
		10.1
	2359	
		2.2
1 Mar	0012	
		9.6
	0037	
		5.1
	0048	

Date	Time (EST)	Speed (cm/sec)
1 Mar	0048	
		10.6
	0115	
		5.1
	0126	
		11.4
	0152	
		2.6
	0218	
		11.9
	0240	
		10.9
	0300	
		5.7
	0337	
		6.3
	0354	
		11.6
	0435	
		12.8
	0457	
		9.3
	0536	
		16.8
	0556	
		10.2
	0645	
		6.8
	0708	
		10.0
	0750	
		9.6
	0819	
		12.6
	0908	
		11.2
	0932	
		10.2
	1024	
		12.1
	1048	
		8.5
	1145	
		11.5
	1223	

Transect 4: DROGUE CHARLIE (10 meters)

Date	Time (EST)	Speed (cm/sec)
28 Feb	1319	
		25.0
	1349	
		29.8
	1417	
		22.0
	1445	
		27.6
	1513	
		24.6
	1538	
		26.2
	1635	
		27.7
	1708	
		27.0
	1741	
		26.0
	1812	
		27.0
	1839	
		24.3
	1909	
		24.4
	1939	
		22.0
	2008	
		22.8
	2038	
		16.8
	2104	
		14.2
	2200	

Date	Time (EST)	Speed (cm/sec)
28 Feb	2200	
		10.2
	2233	
		10.0
	2301	
		9.0
	2332	
		8.8
1 Mar	0005	
		7.3
	0042	
		8.7
	0120	
		5.9
	0158	
		7.8
	0247	
		9.6
	0345	
		11.8
	0447	
		11.4
	0546	
		8.0
	0656	
		8.1
	0805	
		8.6
	0920	
		9.6
	1042	
		9.4
	1159	



Drogue Travel Time - Transect 5

Figure A-5

Transect 5: DROGUE PAPA (200 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
2 Mar	0946			
				Launch
	0951			
				Settling
	1341			
		9.3	338	
	1424			
		13.9	311	
	1534			
		13.9	335	
	1646			
		59.7	338	
	1705			
		11.3	340	
	1740			
		8.2	347	
	1956			
		16.0	358	
	2033			
		11.8	344	
	2115			
		11.8	352	
	2152			
		14.9	348	
	2238			
		17.0	344	
	2320			
		11.8	343	
3 Mar	0025			
		18.0	343	
	0108			
		16.0	334	
	0210			
		20.1	341	
	0253			
		13.9	348	
	0350			
		16.0	356	
	0440			
		16.5	353	
	0548			
		12.4	338	
	0650			
		11.8	332	
	0800			

Transect 5: DROGUE PAPA (200 meters) (cont.)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
3 Mar	0800			
		13.4	331	
	1000			
		12.9	320	
	1117			
		10.3	331	
	1240			
		35.5	000	
	1655			
		6.2	338	
	2037			
		5.1	280	Strong Wind
5 Mar	1055			

Average Speed	=	13.9 cm/sec
Total Travel Time	=	27.94 hours
Mean Direction	=	342°T
Displacement	=	13.5 kilometers
Total Distance	=	13.8 kilometers

Transect 5: DROGUE UNIFORM (500 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
2 Mar	0920			
				Launch
	0932			
				Settling
	1320			
		8.7	295	
	1431			
		11.8	318	
	1542			
		20.6	329	
	1603			
		20.1	325	
	1648			
		103.0	340	
	1658			
		7.2	335	
	1847			
		28.3	355	
	1907			
		13.4	350	
	2005			
		5.1	345	
	2123			
		1.5	355	
3 Mar	0417			
		9.3	346	
	0624			
		7.2	346	
	0935			
		2.1	194	
	1221			
		9.3	267	
	1734			
		17.5	315	
	1816			
		15.9	295	
	1950			

Average Speed	=	8.2 cm/sec
Total Travel Time	=	30.51 hours
Mean Direction	=	318°T
Displacement	=	7.4 kilometers
Total Distance	=	8.9 kilometers

Transect 5: DROGUE NOVEMBER (1000 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
2 Mar	0856	-	-	
	0911	-	-	
	1326	-	-	
	1440	-	-	
	1552	21.1	335	
	1708	16.0	335	
	1749	16.0	335	
	1902	15.4	350	
	2015	9.8	336	
	2135	13.9	350	
	2300	8.7	340	
3 Mar	0047	7.2	330	
	0230	40.2	330	
	0412	15.4	337	
	0618	14.9	332	
	0837	15.4	325	
	0927	12.4	316	
	1229	12.9	316	
	1718	13.9	320	
	2017	22.1	313	
5 Mar	1126			

Average Speed = 14.4 cm/sec
Total Travel Time = 29.42 hours
Mean Direction = 325°T
Displacement = 26.6 kilometers
Total Distance = 28.9 kilometers

Transect 5: DROGUE LIMA (1400 meters)

Date	Time (EST)	Speed (cm/sec)	Direction (°T)	Remarks
3 Mar	0900			
				Launch
	0917			
				Settling
	1143			
		7.2	165	
	1755			
		3.6	256	
	1918			
		5.7	308	
5 Mar	1021			

Average Speed	=	5.7 cm/sec
Total Travel Time	=	46.65 hours
Mean Direction	=	291°T
Displacement	=	6.85 kilometers
Total Distance	=	9.6 kilometers

APPENDIX B

WIND DATA

	Date	Time (EST)	Speed (mph)	Direction
Transect 1	14 Feb	1514	3-4	N
		1936	CALM	
		2002	CALM	
	16 Feb	0950	12	NE
		1130	8	NE
		1420	6-8	NE
		1740	20	NE
		2345	30	NE
	17 Feb	1030	220	NE
		1437	12	NE
	18 Feb	0900	8	NE
		0933	12-15	NE
Transect 2	21 Feb	1528	CALM	
		1722	CALM	
		2116	CALM	
		2205	CALM	
		2308	9	SE
	22 Feb	0008	11	SE
		0228	8-11	SSE

	Date	Time (EST)	Speed (mph)	Direction
Transect 2	22 Feb	0332	10-12	SSE
		0740	8	SE
		0828	12	SE
		0941	5	SE
		1113	10	SSE
		1114	8	SSE
		1710	10	NE
		2046	18-20	NE
		2158	15-18	NE
	23 Feb	0016	20	NE
		0608	10	E
		0822	12	NE by N
		1048	15-16	NE
		1240	16	ENE
		1456	16	ENE
		1642	12-15	ENE
	24 Feb	0742	16	ESE
		1012	16	SE-SSE
		1800	8	SSE
	25 Feb	0950	3-5	WSW
		1235	3-4	NE
		1320	5-10	NE
Transect 3, 4, 5	28 Feb	0800	12	E

	Date	Time (EST)	Speed (mph)	Direction
Transect 3, 4, 5	28 Feb	1037	12	E by S
		1146	12-15	ESE
		1622	-	ESE
		1754	12	ESE
		1805	12	E
		1824	12-15	ESE
		1925	12	E
		2217	18	ESE
	1 Mar	0022	220	ESE
		0041	12	E
		0222	19	ESE
		0413	15	ESE
		0525	15	SSE
		0816	12	SSE
		0843	15	SE
		1037	15	ESE
		1119	22-28	SE
		2203	8	ESE
	2 Mar	0715	6	SSE
		1615	8	SSE
	3 Mar	0245	6	E
		0500	5	E
		1440	12-15	E

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AUTEC Deep water range Torpedo tracking Oceanographic data Current measurements Drogues (parachutes) Flow patterns Vertical current gradients Eddy motion (turbulence)						

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3. Torpedo Tracking
4. Oceanographic Data
5. Current Measurements

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